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U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
National Institutes of Health

Radiation Dosimetry and Organ Doses from Imaging

May 2011

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  - Radiation dosimetry in imaging
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Radiation Imaging

X-ray

- Discovery
  - Discovered by Wilhelm Rontgen (1895) (“X” is indicating “unknown”)
- Findings
  - Travels in straight lines
  - Make shadows of absorbing material on photosensitive paper!

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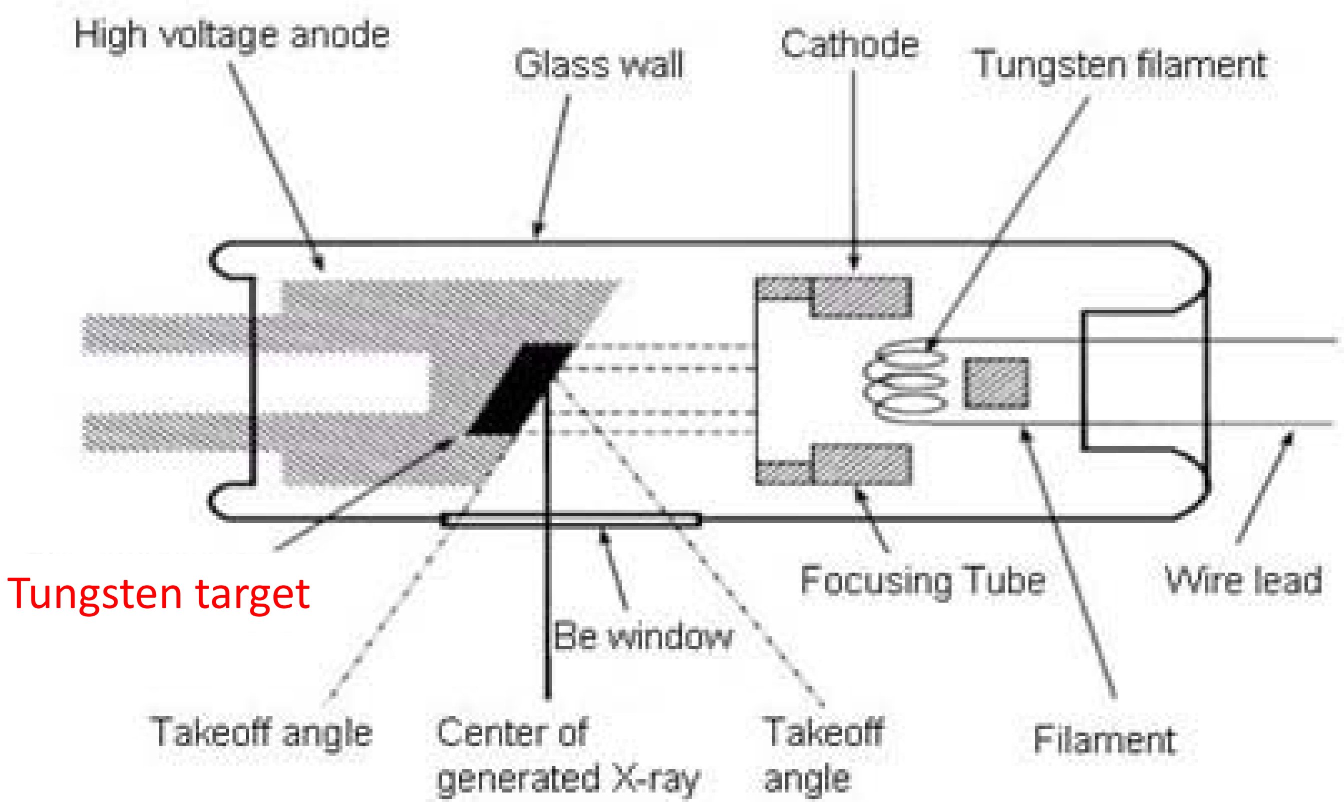
X-ray generation



X-ray tube

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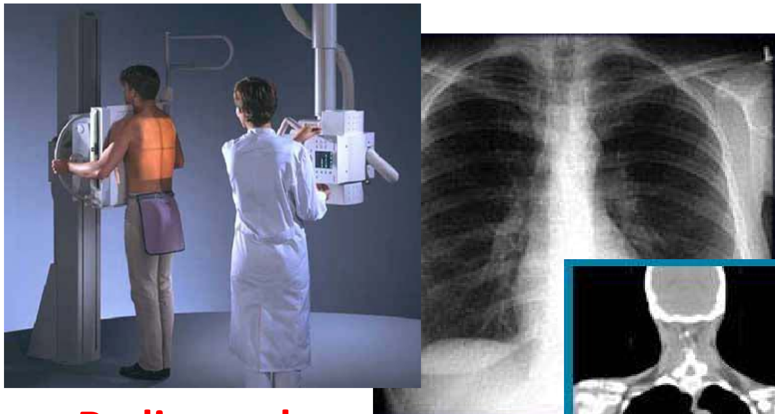
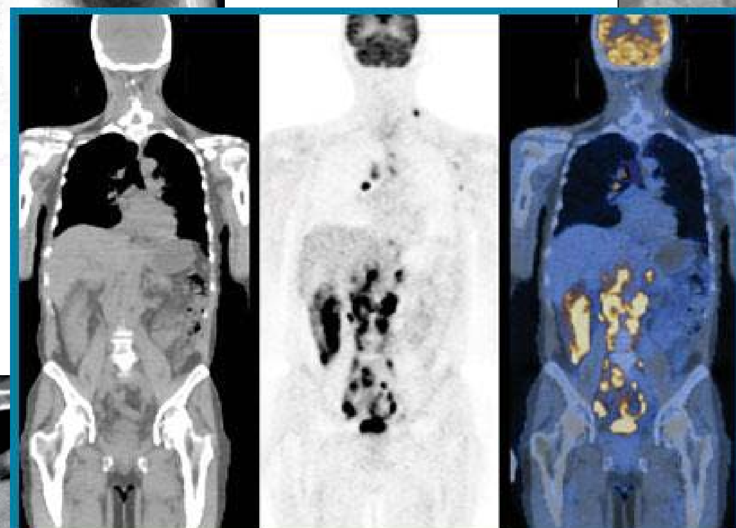
Different imaging modalities



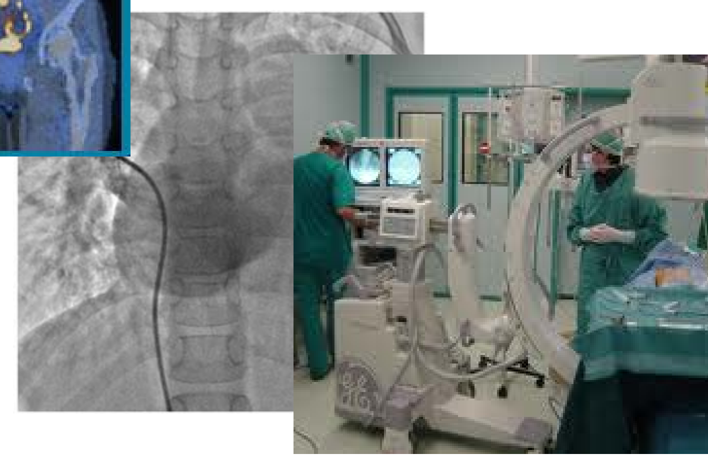
Radiography

Mammography



Nuclear Medicine Imaging*

Computed Tomography



Interventional fluoroscopy

*Use different mechanism from other imaging modalities

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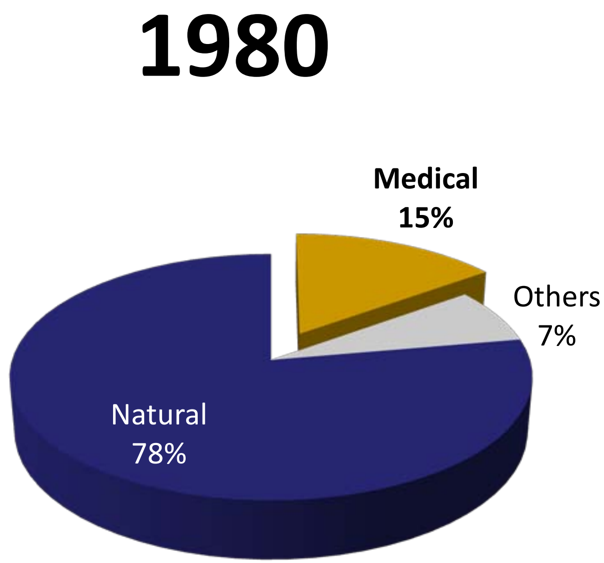
Current status of procedures (US 2006)*

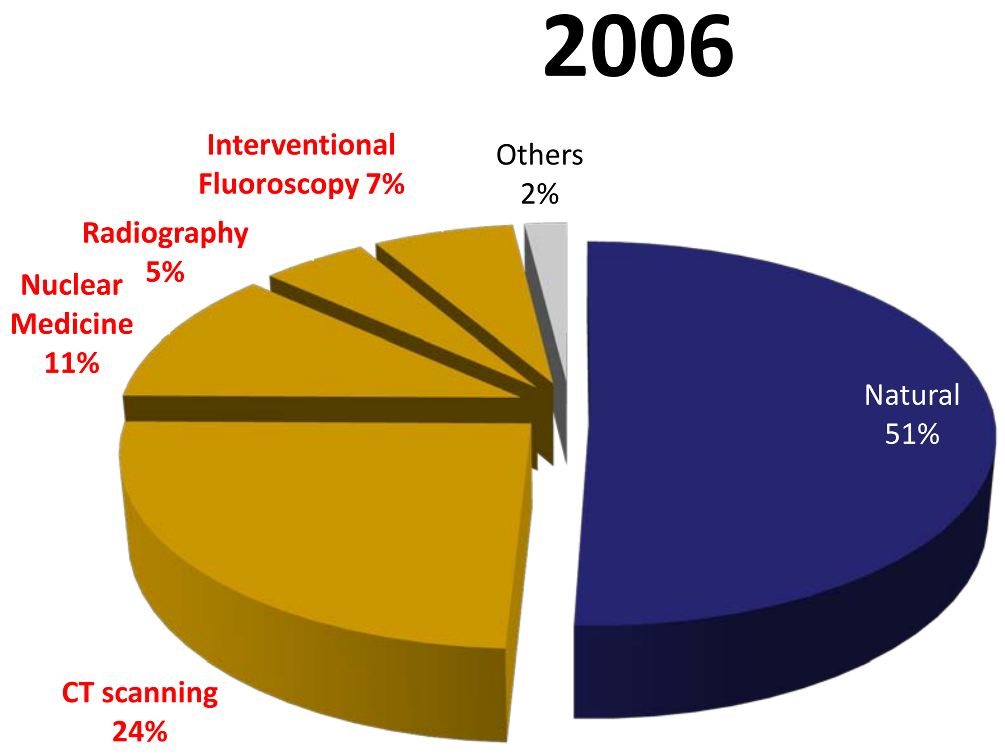
Modality	Number of procedures	%
Radiography	293 million	74
CT	67 million	17
Nuclear Medicine	18 million	5
Interventional Fluoroscopy	17 million	4
Radiotherapy	1 million patients	NA

* Mettler et al. Radiology (2009)

Changes in U.S. medical radiation exposure*



Total 3.6 mSv (effective dose) per capita



Total 6.2 mSv (effective dose) per capita

* NCRP Report 160, 2009

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Typical organ doses for patient*

Study type	Relevant organ	Organ dose (mGy)
Dental radiography	Brain	0.005
PA chest radiography	Lung	0.01
Lateral chest radiography	Lung	0.15
Screening mammography	Breast	3
Adult abdominal CT	Stomach	10
Barium enema	Colon	15
Neonatal abdominal CT	Stomach	20

* Brenner et al. NEJM (2007)

Typical organ doses for patient*

Type of examination	Effective dose (mSv)[f]
Radiography (single radiograph)[a]	
Skull AP or PA	0.015 (1)
Chest PA	0.013 (1)
T-spine AP	0.27 (20)
L-spine AP	0.44 (30)
Abdomen AP	0.46 (35)
Pelvis AP	0.48 (35)
Mammography (4 views)[b]	
Screening	0.2 (15)

* Linet et al. PR (2009)

Typical organ doses for patient*

Type of examination	Effective dose (mSv)[f]
Dental radiography[c]	
Intra oral	0.013 (1)
Panoramic	0.012 (1)
Diagnostic fluoroscopy procedures	
Barium swallow[a]	1 (70)
Barium meal[a]	2 (150)
Barium enema[a]	5 (350)
Angiography—cerebral[c]	2 (150)
Angiography—cardiac[c]	7 (500)

* Linet et al. PR (2009)

Typical organ doses for patient*

Type of examination	Effective dose (mSv)[f]
Computed tomography[d]	
Head	2 (150)
Chest	10 (750)
Abdomen	10 (750)
Pelvis	7 (500)
Abdomen/pelvis	15 (1,100)
C-spine	5 (400)
T-spine	8 (550)
L-spine	7 (500)

* Linet et al. PR (2009)

Typical organ doses for patient*

Type of examination	Effective dose (mSv)[f]
Diagnostic nuclear medicine[e]	
Bone (^{99m}Tc-phosphate)	3 (200)
Heart (^{201}Tl thallous chloride)	13 (950)
Lung (^{99m}Tc-MAA)	0.9 (70)
Tumor-PET(^{18}F-FDG)	7 (500)
Kidney (^{99m}Tc-MAG3)	0.6 (40)
Thyroid (^{99m}Tc-Pertechnetate)	0.9 (70)

* Linet et al. PR (2009)

Radiation dosimetry in imaging

What is Dosimetry?

- Definition: determination of radiation dose resulting from the interaction of ionizing radiation with matter

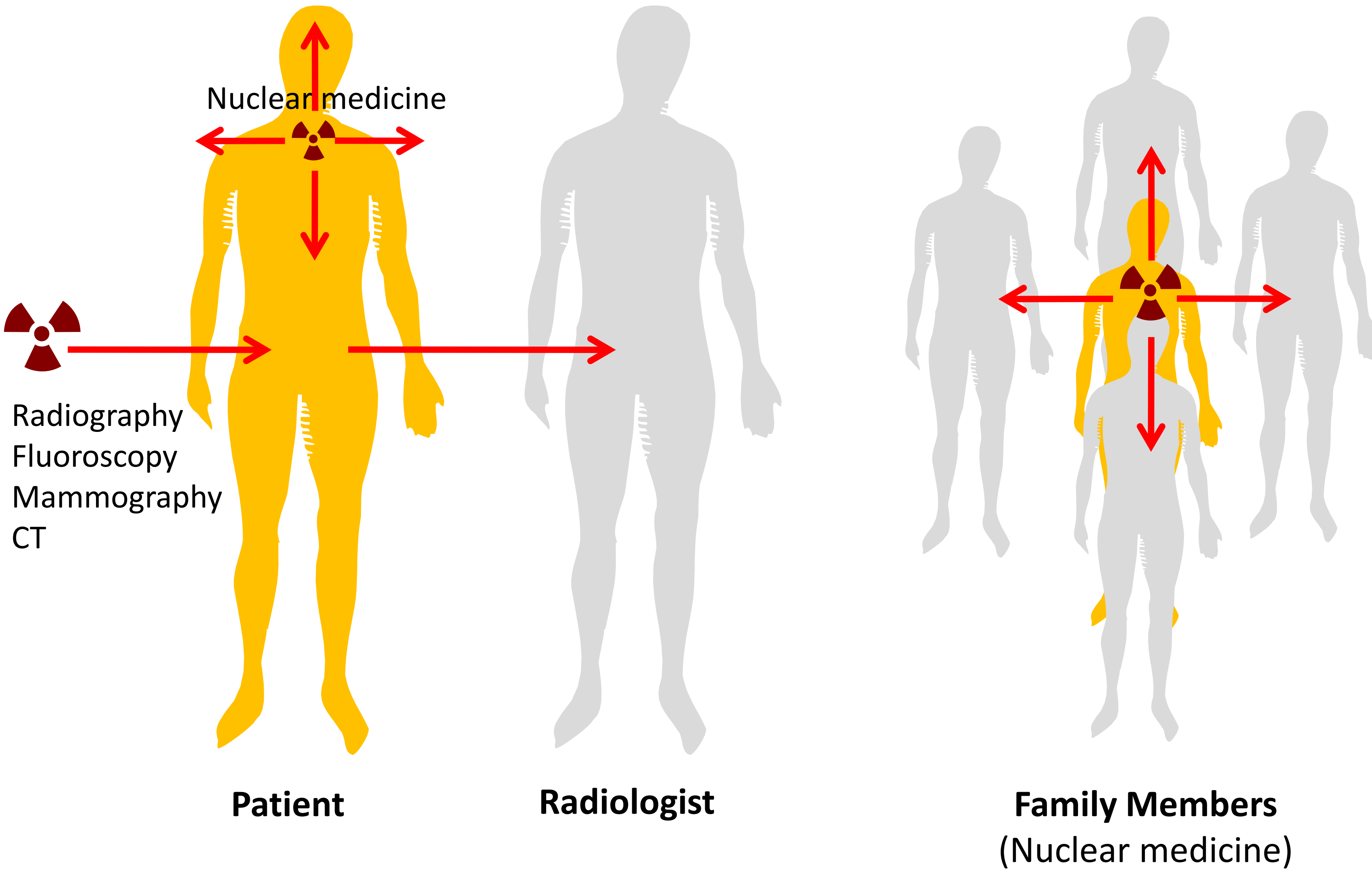
Radiation

- Radiation type
- Energy
- Direction
- Collimator

Human

- Age
- Sex
- Body size
- Posture
- Shielding

Who’s getting radiation dose?



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Dosimetric quantities*

Kinetic energy deposited in matter

Organ Absorbed Dose (Gy) $\xrightarrow{w_R}$ **Equivalent Dose (Sv)** $\xrightarrow{w_T}$ **Effective Dose (Sv)**

w_R: Radiation Weighting Factor

w_T: Tissue Weighting Factor

$$H_T = \sum_R w_R D_{T,R}$$

$$E = \sum_T w_T \left[\frac{H_T^M + H_T^F}{2} \right]$$

Organ Absorbed Dose (Gy) $\Updownarrow$ **Kerma (Gy)**

Kinetic energy released in matter

* ICRP Publication 103 (2007)

Radiation weighting factor*

Table 2. Recommended radiation weighting factors.

Radiation type	Radiation weighting factor, w_R
Photons	1
Electrons[a] and muons	1
Protons and charged pions	2
Alpha particles, fission fragments, heavy ions	20
Neutrons	A continuous function of neutron energy (see Fig. 1 and Eq. 4.3)

$$w_R = \begin{cases} 2.5 + 18.2\, e^{-[\ln(E_n)]^2/6}, & E_n < 1 \text{ MeV} \\ 5.0 + 17.0\, e^{-[\ln(2E_n)]^2/6}, & 1 \text{ MeV} \leqslant E_n \leqslant 50 \text{ MeV} \\ 2.5 + 3.25\, e^{-[\ln(0.04E_n)]^2/6}, & E_n > 50 \text{ MeV} \end{cases}$$

* ICRP Publication 103 (2007)

Tissue weighting factor*

Table 3. Recommended tissue weighting factors.

Tissue	w_T	$\sum w_T$
Bone-marrow (red), Colon, Lung, Stomach, Breast, Remainder tissues*	0.12	0.72
Gonads	0.08	0.08
Bladder, Oesophagus, Liver, Thyroid	0.04	0.16
Bone surface, Brain, Salivary glands, Skin	0.01	0.04
	Total	1.00

* Remainder tissues: Adrenals, Extrathoracic (ET) region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate (♂), Small intestine, Spleen, Thymus, Uterus/cervix (♀).

* ICRP Publication 103 (2007)

Dosimetric quantities*

Kinetic energy deposited in matter

Individualized organ dose

w_R

Radiation Weighting Factor

Equivalent Dose (Sv)

w_T

Tissue Weighting Factor

Effective Dose (Sv)

$$H_T = \sum_R w_R D_{T,R}$$

$$E = \sum_T w_T \left[\frac{H_T^M + H_T^F}{2} \right]$$

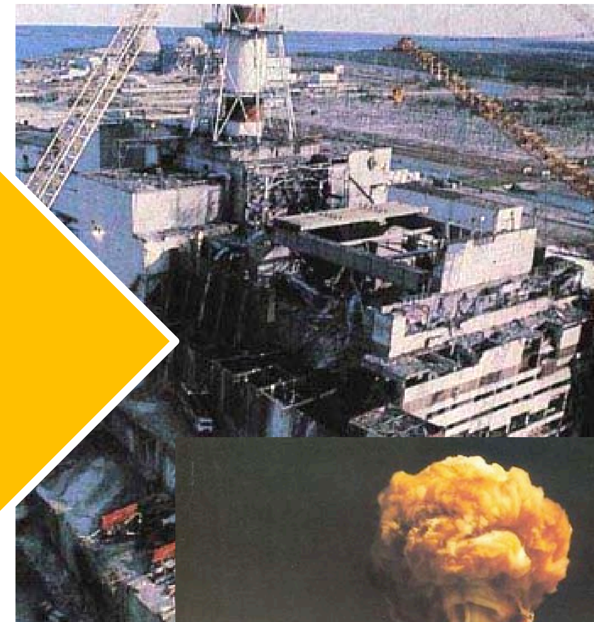
Kerma (Gy)

Kinetic energy released in matter

* ICRP Publication 103 (2007)

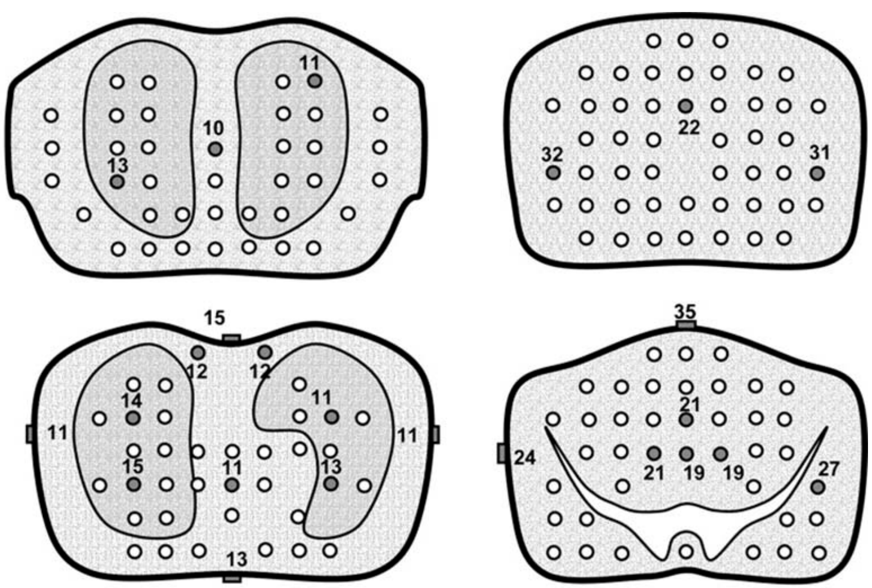
Organ dose estimation for medically-exposed patients

- Controlled
- Relatively well documented



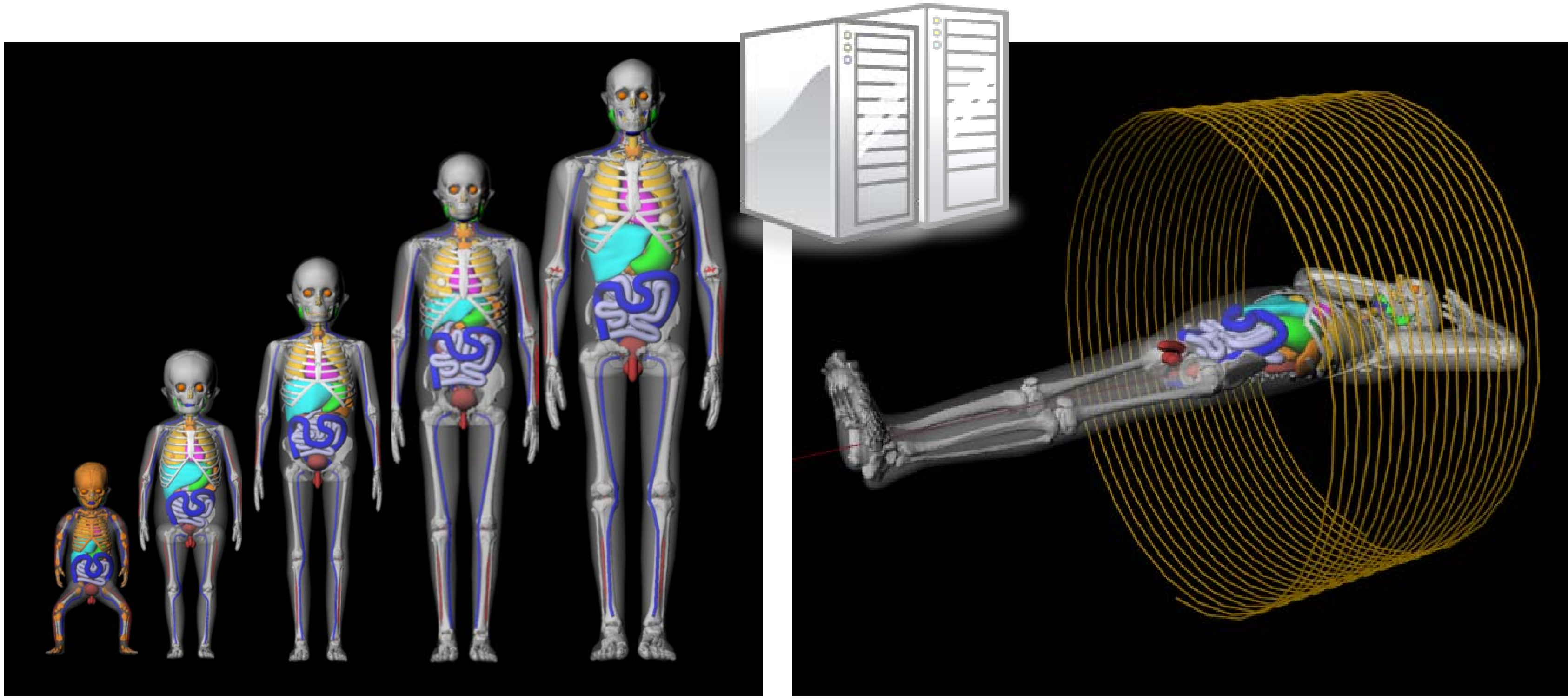
How to obtain the individualized organ dose?

(1) Measurement



- Expensive
- Substantial man-hour
- Not individualized

(2) Calculation



- 30+ organ doses
- Bone marrow dose
- Highly individualized

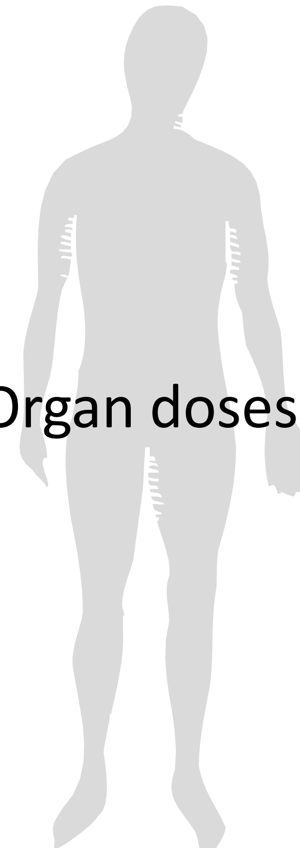
- Cost-effective
- Fewer man-hour
- More flexible

(3) Conversion Factor

Measurement

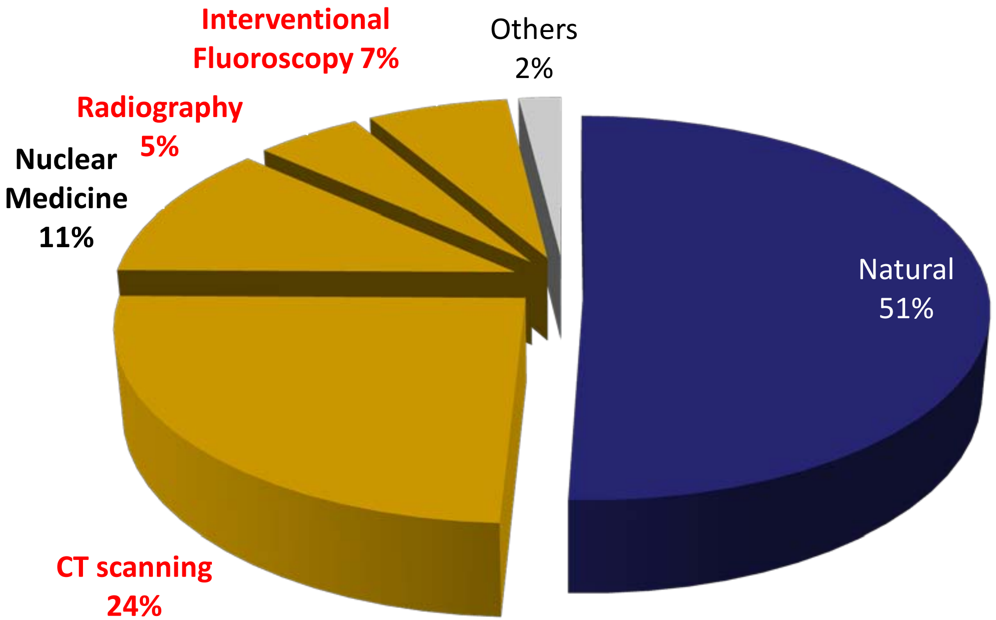
Conversion Factor

Organ doses



Derived from computer simulations

Dosimetry in major imaging modalities



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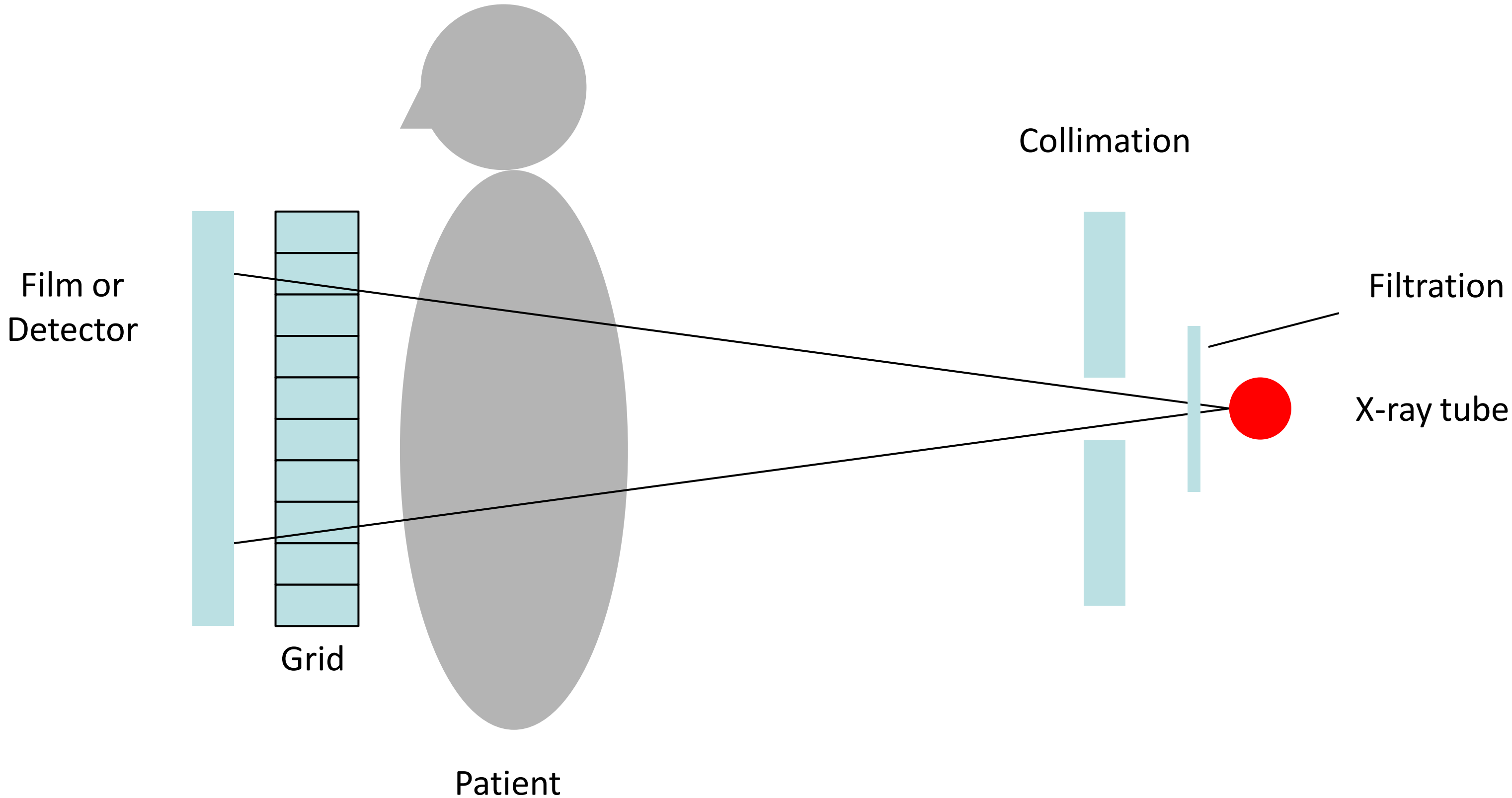
Radiography



Factors affecting dose in radiography

- Beam energy
  - Primarily depends on the tube potential (kVp) and filtration
  - Higher energy beam is more penetrating to reach image receptor
  - Lower tube current or shorter imaging time
  - Reduce the dose to the patient
- Filtrations
  - Total filtration = Inherent filtration + Added filtration
  - Remove low-energy x-ray which can be absorbed by the patient
- Collimation
  - Limit the exposed area in the patient
  - Reduce the scattered radiation and increase image contrast

Factors affecting dose in radiography

- Grids
  - Reduce the scattered radiation contribution to improve image contrast
  - Also absorb a portion of non-scattered radiation
  - Cause increase current and time giving more doses to the patient
- Patient size
  - Need more radiation to get an acceptable image for thicker patient
  - Technique charts displaying suggested technique factors for different exams and patient thicknesses will be helpful

Organ dose estimation: Conversion factors

- "Handbook of selected tissue doses for projections common in diagnostic radiology" (Rosenstein, FDA89-8031, 1988)
  - Developed from adult male and female computational phantoms coupled with Monte Carlo transport technique
  - Provide organ doses per unit exposure (measurable) for comprehensive technique factors

Organ dose estimation: Conversion factors

TABLE 24. PA CHEST - SID: 72" (183 cm); FIELD SIZE at FILM: 14" X 17" (35.6 cm X 43.2 cm)

MALE	TISSUE DOSES (mrad) and CANCER DETRIMENT INDEX for 1 R EXPOSURE at SKIN ENTRANCE (FREE-IN-AIR)[a,b]											
HVL (mm Al) ⟶	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
LUNGS	124	216	301	375	439	493	539	578	610	637	660	678
ACTIVE BONE MARROW	27	49	71	92	113	131	149	165	180	194	207	219
THYROID	4.0	11	21	30	40	49	57	64	70	75	79	82
TRUNK TISSUE	52	82	109	132	152	170	185	199	210	221	230	238
CDI (10^{-5})	0.65	1.09	1.49	1.85	2.16	2.44	2.68	2.88	3.06	3.22	3.36	3.48
TESTES	+	+	+	+	+	0.1	0.1	0.1	0.1	0.1	0.1	0.2

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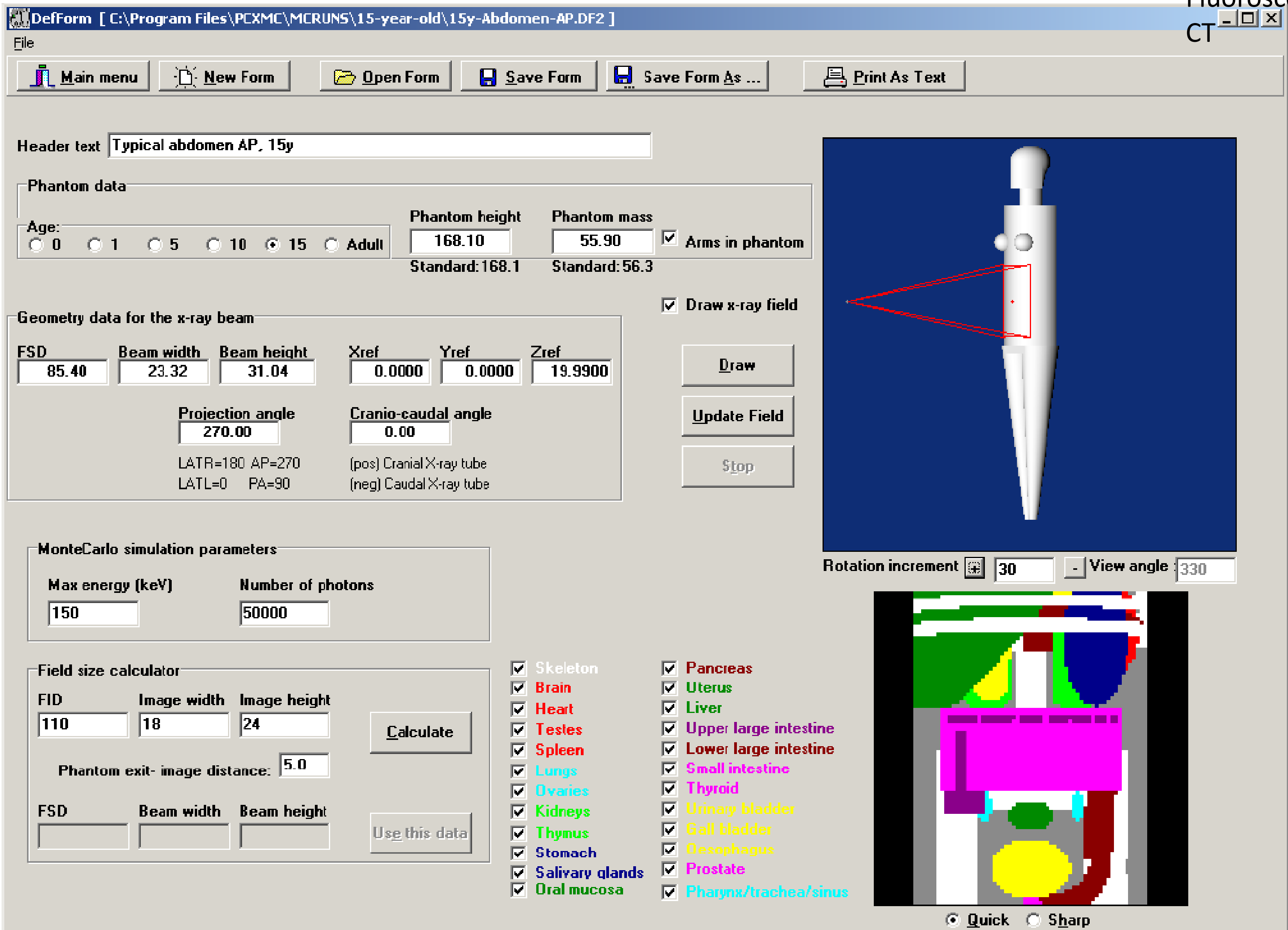
Organ dose estimation: PCXMC

- A commercial computer program for calculating patients' organ and effective doses in radiography examinations
  - Developed by Tapiovaara et al. (STUK, Finland)
  - Current version, PCXMC 2.0 (released in Nov 2008)
  - Based on the computational phantoms (Cristy and Eckerman, 1987) coupled with Monte Carlo transport technique

Graphical interface for user input of technique factors

Radiography
Mammography
Fluoroscopy
CT



Radiography
Mammography
Fluoroscopy
CT

Input measurement and organ dose output

Patient input dose

Input dose value: 1.0000 mGy

Incident air kerma value used in calculations: 1.0000 mGy

[Corresponds to about 9.7mAs]

Input dose quantity and unit:
- (•) Incident air kerma (mGy)
- ( ) Dose-Area Product (mGycm^2)
- ( ) Entrance exposure (mR)
- ( ) Exposure -Area Product (Rcm^2)
- ( ) Current -Time Product (mAs)

(Input dose quantities are for measurements without BSF)

OK ! Cancel

PCXMC- Dose Calculation

File Run

Main menu | Change X-ray Spectrum | Open MC data for dose calculation | Print | Save As ...

X-ray tube potential: 120 kV Filtration: 3 mm Al + 0,1 mm Cu
Anode angle: 17 deg

File: C:\Program Files\PCXMC\MCRUNS\Adult\adult-chest-PA200000.en2
ypical chest PA, Adult Phantom: Adult , Arms included. Simulation: Photons/Energy level: 200000 Maximum energy: 150 keV
Projection angle (LATL=0,PA=90,LATR=180,AP=270): 90.000 Obl. angle: 0.000
Field width: 30.10 cm and height: 37.60 cm FSD: 160.000 cm Ref.point (x,y,z(cm)): (0.000, 0.000, 52.000)
Phantom height: 178.600 cm and mass: 73.200 kg Scaling factors sx(=sy): 1.000 and sz: 1.000
Incident air kerma:..... 0.150 mGy Tube voltage: 120 kV Filter:.....3 mm Al + 0,1 mm Cu

Organs	Dose (mGy)	Error (%)	Organs	Dose (mGy)	Error (%)
Active bone marrow	0,052206	0,1	(Scapulae)	0,400557	0,4
Adrenals	0,154045	1,7	(Clavicles)	0,060160	1,4
Brain	0,000822	3,3	(Ribs)	0,288670	0,2
Breasts	0,035366	0,9	(Upper arm bones)	0,035092	1,0
Colon (Large intestine)	0,003454	1,5	(Middle arm bones)	0,039175	1,0
(Upper large intestine)	0,005363	1,6	(Lower arm bones)	0,006518	1,8
(Lower large intestine)	0,000929	4,3	(Pelvis)	0,002112	2,1
Extrathoracic airways	0,007761	4,7	(Upper leg bones)	0,000026	18,1
Gall bladder	0,027439	2,1	(Middle leg bones)	0,000001	47,8
Heart	0,058200	0,6	(Lower leg bones)	0,000000	NA
Kidneys	0,092431	0,6	Skin	0,024164	0,2
Liver	0,065439	0,3	Small intestine	0,004068	1,4
Lungs	0,131340	0,2	Spleen	0,124134	0,8
Lymph nodes	0,035024	0,4	Stomach	0,037965	1,1
Muscle	0,027625	0,1	Testicles	0,000001	69,9
Oesophagus	0,081588	1,0	Thymus	0,029615	3,1
Oral mucosa	0,002377	6,2	Thyroid	0,023657	3,7
Ovaries	0,000911	21,3	Urinary bladder	0,000195	17,7
Pancreas	0,073502	1,1	Uterus	0,000731	8,1
Prostate	0,000068	83,9			
Salivary glands	0,004203	3,5	Average dose in total body	0,035716	0,1
Skeleton	0,074937	0,1	Effective dose ICRP60 (mSv)	0,042921	0,3
(Skull)	0,004391	1,5	Effective dose ICRP103 (mSv)	0,045029	0,2
(Upper Spine)	0,044352	1,2			
(Middle Spine)	0,326392	0,3			
(Lower Spine)	0,075329	0,9	Abs. energy fraction (%)	58,042776	

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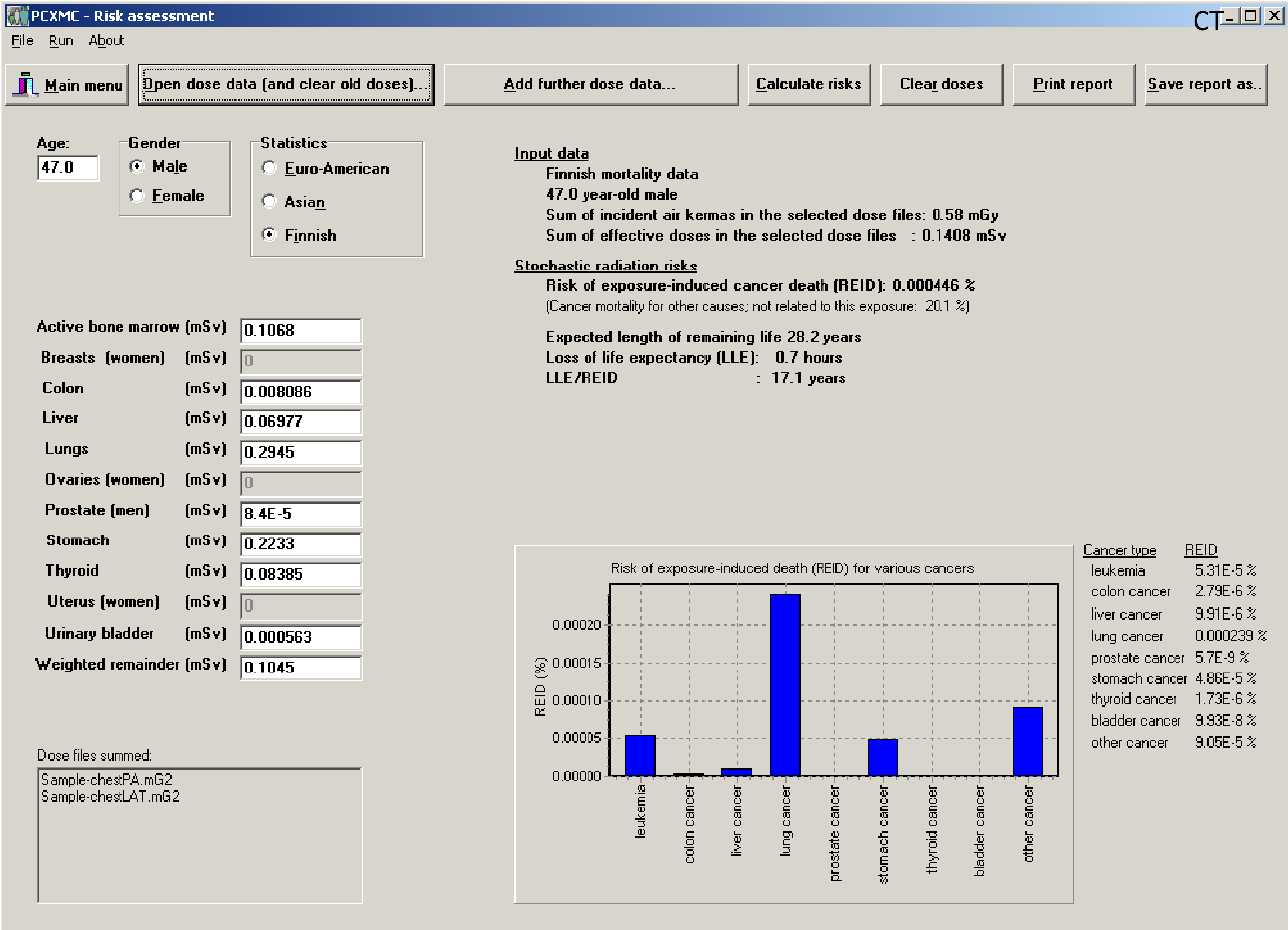
Risk assessment output

Radiography
Mammography
Fluoroscopy
CT



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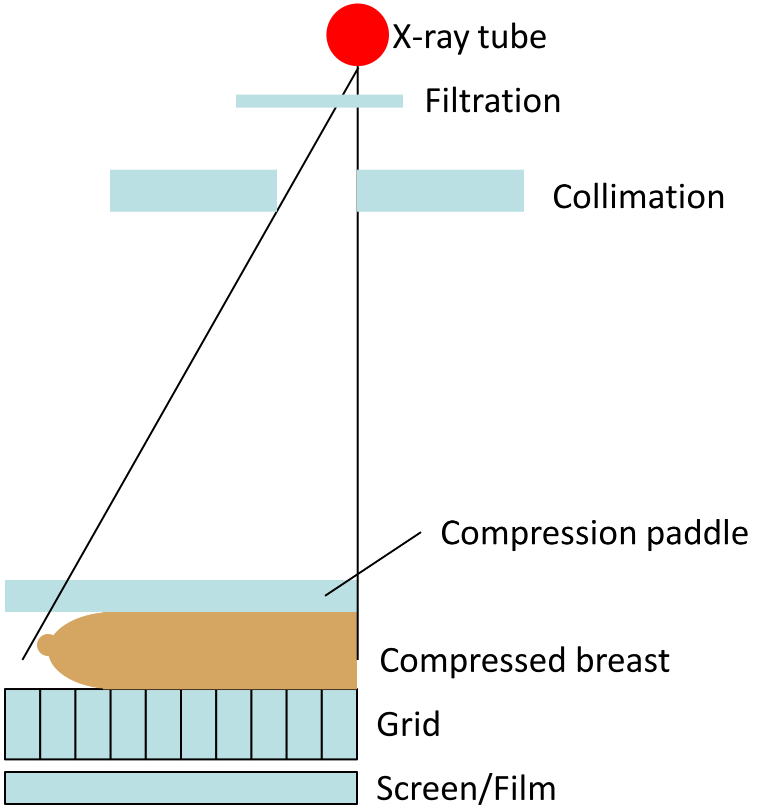
Mammography

- Average (or mean) glandular dose (AGD)
  - Used to describe the dose to the breast
  - Considered to be at greatest risk
  - Replaced traditional quantities (skin dose, midplane breast dose, and etc.)



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Factors affecting dose in mammography

- Beam energy
  - Approximately 24-30 kVp
  - Small difference in beam energy affect breast dose
  - Higher beam energy reduce breast dose

- Target material
  - Molybdenum (18 and 20 keV) and rhodium (20 and 23 keV)
  - Rhodium used for thicker breast

- Filter material
  - Molybdenum and rhodium

Factors affecting dose in mammography

- Grids
  - Reduce the scattered radiation to increase image contrast
  - High contrast images are very important because of similar composition of glandular tissue with surrounding ones

- Magnification
  - Move breast closer to the x-ray tube
  - 1.5 to 2.0 times magnified
  - Increase breast dose according to the inverse square law

Factors affecting dose in mammography

- Breast thickness and tissue composition
  - Thick (or large) breasts or those with dense composition need higher energy beam and longer exposure time, and receive higher AGD

- Compression
  - Provides better imaging geometry
  - Lower AGD to the patient
  - More uniform exposure the breast

Organ dose estimation: Conversion factor

- The average glandular dose, $D_g = D_{gN} \times X_{ESE}$
  X_{ESE}: the entrance skin exposure (measurable)
  D_{gN}: ESE-to-AGD conversion factor (obtained from Monte Carlo simulation)

TABLE 8-6. DgN CONVERSION FACTOR (mRAD PER ROENTGEN) AS A FUNCTION OF HVL AND kVp FOR Mo TARGET/FILTER: 4.5-CM BREAST THICKNESS OF 50% GLANDULAR AND 50% ADIPOSE BREAST TISSUE COMPOSITION*

	kVp							
HVL (mm)	25	26	27	28	29	30	31	32
0.25	122							
0.26	126	128						
0.27	130	132	134					
0.28	134	136	138	139				
0.29	139	141	142	143	144			
0.30	143	145	146	147	148	149		
0.31	147	149	150	151	152	153	154	
0.32	151	153	154	155	156	158	159	160
0.33	155	157	158	159	160	162	163	164
0.34	160	161	162	163	164	166	167	168
0.35	164	166	167	168	169	170	171	172
0.36	168	170	171	172	173	174	175	176
0.37		174	175	176	177	178	178	179
0.38			179	180	181	182	182	183
0.39				184	185	186	186	187
0.40					189	190	191	192

*Adapted from ACR QC Manual, 1999.

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Radiography
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CT

Advanced conversion factor*

Table A3. Dose conversion coefficients (this work) derived for typical protocols by time period and compressed breast thickness (CBT).

Period	Technique	Target-filter	HVL[a] or filtration	CBT (cm)	kV min	kV max	Dose coefficient D_{gN} min	Dose coefficient D_{gN} max
1960-1964	Egan	W-Al	0.9 mm Al inherent	3	22	24	0.305	0.353
				5	26	35	0.258	0.377
				8	26	35	0.169	0.255
	Gershon-Cohen	W-Al	1.5 mm Al 1mm inherent	3	25	30	0.449	0.535
				5	25	30	0.294	0.365
				8	25	30	0.192	0.243
1965-1969	Egan	Mo-Mo	HVL = 0.4	3	26	30	0.305	0.309
				5	26	30	0.190	0.194
				8	26	30	0.123	0.126
			HVL = 0.61	3	26	30	0.449	0.453
				5	26	30	0.290	0.297
				8	26	30	0.189	0.195
			0.78 mm Al	3	26	30	0.347	0.375
				5	26	30	0.217	0.238
				8	26	30	0.141	0.156

* Thierry-Chef et al. (in review)

Radiography
Mammography
Fluoroscopy
CT

Period	Technique	Target-filter	HVL[a] or filtration	CBT (cm)	kV min	kV max	Dose coefficient D_{gN} min	Dose coefficient D_{gN} max
1980-1984	Xeroradiography	W-Al	HVL = 1	3	40	55	0.652	0.643
				5	40	55	0.469	0.470
				8	40	55	0.323	0.329
	Screen Film (Low-Dose)	Mo-Mo	HVL = 0.31	3	28	-	0.252	-
				5	28	-	0.156	-
				8	28	-	0.101	-
1985-1989	Xeroradiography	W-Al	HVL = 1.26	3	44	45	0.714	0.713
				5	44	45	0.524	0.524
				8	44	45	0.365	0.366
	Screen Film (Low-Dose)	Mo-Mo	HVL = 0.37	3	27	29	0.286	0.289
				5	27	29	0.178	0.180
				8	27	29	0.115	0.117
		Mo-Mo	HVL = 0.49	3	27	29	0.368	0.370
				5	27	29	0.232	0.234
				8	27	29	0.151	0.152
1990-1999	Xeroradiography	W-Al	HVL = 1.3	3	46	-	0.726	-
				5	46	-	0.536	-
				8	46	-	0.375	-
	Screen Film (Low-Dose)	Mo-Mo	HVL = 0.35	3	25	28	0.269	0.274
				5	25	28	0.166	0.170
				8	25	28	0.108	0.111
			HVL = 0.37	3	25	28	0.283	0.287
				5	25	28	0.175	0.179
				8	25	28	0.113	0.116
2000+	Screen Film (Low-Dose)	Mo-Mo	0.03 mm Mo	3	24	28	0.241	0.252
				5	24	28	0.149	0.156
				8	24	28	0.097	0.101

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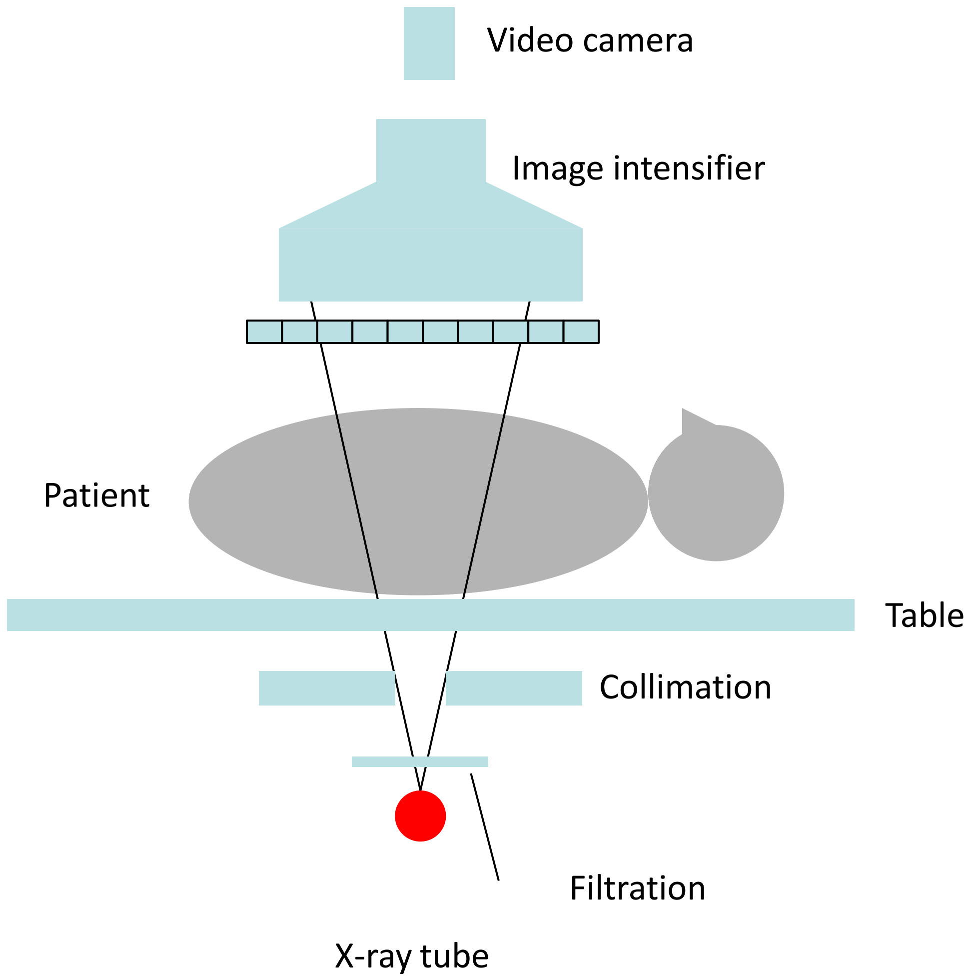
Fluoroscopy



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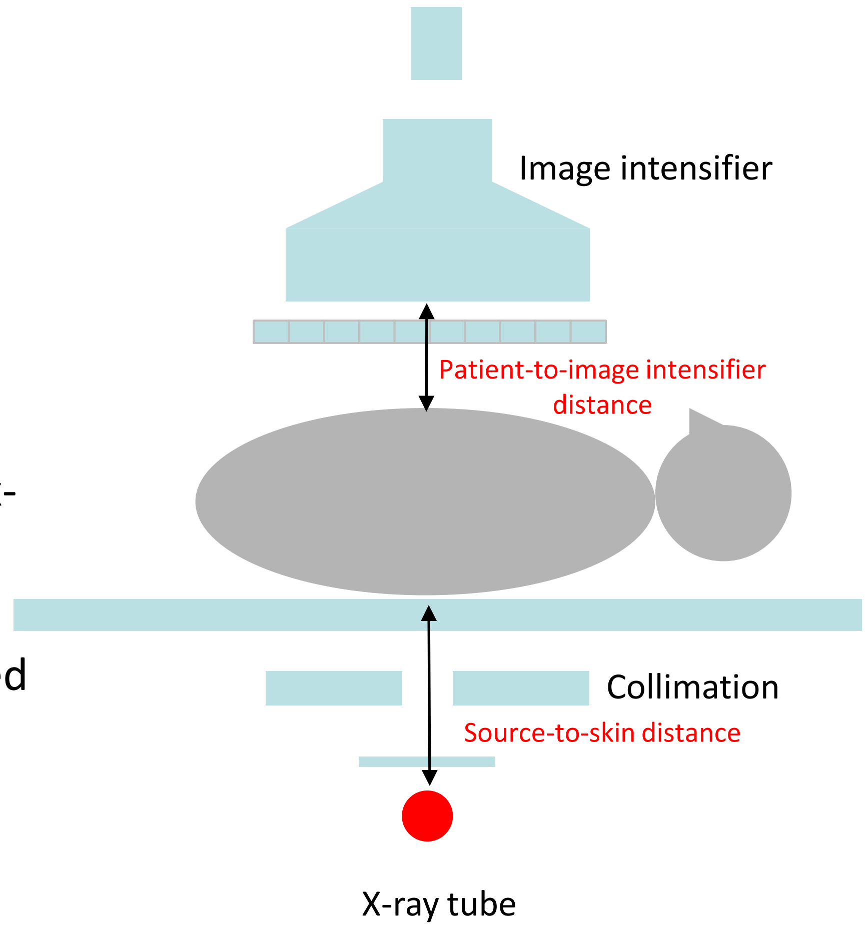
Factors affecting dose in fluoroscopy

- Beam energy
  - Higher kVp results in more penetrating beam and reduces tube current
- Collimation
  - Use the smallest field to image only the area of interest
  - Reduce the scattered radiation and leads to higher-quality images

Factors affecting dose in fluoroscopy

- Increase source-to-skin distance
  - Reduce the patient dose according to inverse square law
- Decrease patient-to-image intensifier distance
  - Reduce the patient dose since lower x-ray fluence is needed for acceptable image quality
  - Low image quality due to the increased scattered radiation



Factors affecting dose in fluoroscopy

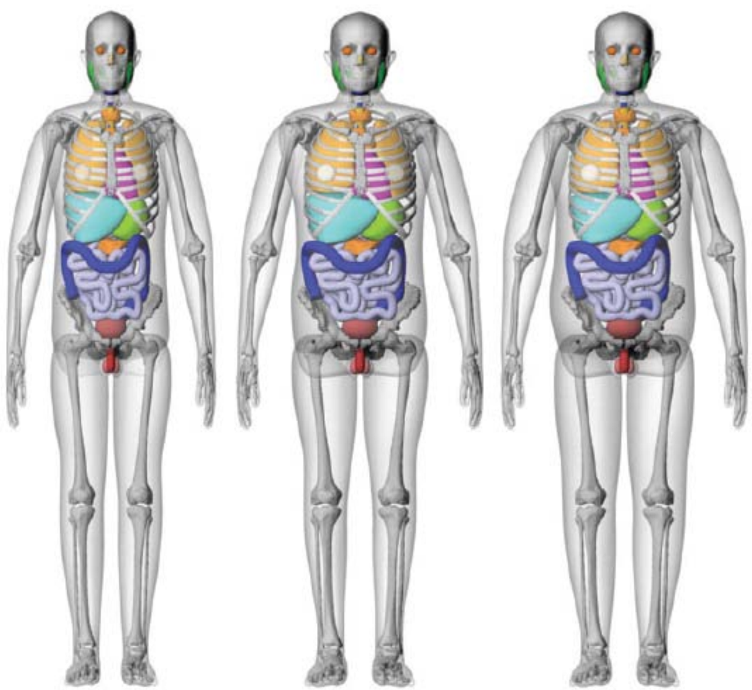
- Image magnification
  - Move the image intensifier farther from the patient or
  - Move x-ray source closer to patient
  - Increase the patient dose
- Grids
  - Reduce the scattered radiation to increase image contrast
  - Patient doses increase by a factor or two or more
- Patient size
  - kVp and tube current must be increased for thicker patients

Factors affecting dose in fluoroscopy

- Beam-on time
  - Directly proportional to the patient dose
  - Several techniques to reduce beam-on time
    - Being aware of the amount of the beam-on time
    - Last-frame-hold feature (display the last image after the beam is off)
    - Aggressive use of low frame rate pulsed fluoroscopy
    - Release the fluoroscopy pedal frequently

Organ dose estimation: conversion factor*

- Heavily rely on computer simulation using Monte Carlo transport technique and computational human phantoms



10% 50% 90%

Table 2. Organ dose conversion coefficients (mGy per Gy cm^2) and

AP projection	60 kVp 3.5 mm Al UFHADM weight percentile 10%	50%	90%
Organs			
Colon	6.04E-03 (0.67%)	5.51E-03 (0.63%)	5.61E-03 (0.63
Lung	4.70E-01 (0.05%)	2.83E-01 (0.06%)	1.45E-01 (0.08
Stomach	2.33E-01 (0.15%)	1.85E-01 (0.15%)	1.10E-01 (0.19
Bladder	8.88E-05 (10.14%)	7.53E-05 (9.21%)	6.52E-05 (10.62
Liver	1.74E-01 (0.10%)	1.32E-01 (0.10%)	8.28E-02 (0.13
Esophagus	2.56E-01 (0.21%)	1.77E-01 (0.23%)	8.71E-02 (0.32
Thyroid	2.34E-02 (1.26%)	2.04E-02 (1.19%)	1.81E-02 (1.25
Gonads	4.71E-05 (20.47%)	7.74E-05 (18.29%)	3.31E-05 (24.1
Skin	8.07E-02 (0.03%)	7.26E-02 (0.03%)	6.56E-02 (0.03
Brain	2.68E-04 (2.77%)	2.64E-04 (2.40%)	2.22E-04 (2.65
Kidneys	1.27E-02 (0.62%)	1.00E-02 (0.63%)	6.58E-03 (0.77
Salivary glands	2.55E-03 (1.94%)	3.45E-03 (1.46%)	2.40E-03 (1.81
Adrenals	4.52E-02 (0.93%)	3.31E-02 (0.96%)	1.95E-02 (1.24
Gall bladder	2.90E-02 (0.83%)	2.46E-02 (0.80%)	1.88E-02 (0.91

* Johnson et al. PMB (2009)

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Dose estimation: Skin dose

- Direct dose measurement
  - Thermoluminescent dosimeter (TLD)
  - X-ray film
- Real-time direct dose measurement
  - MOSFET dosimeter
- Indirect dose measurement
  - Measure dose at the collimator port
  - Dose derived from system parameters (e.g. PEMNET system)
- Real-time parameters
  - Fluoroscopic time
  - Dose-area-product

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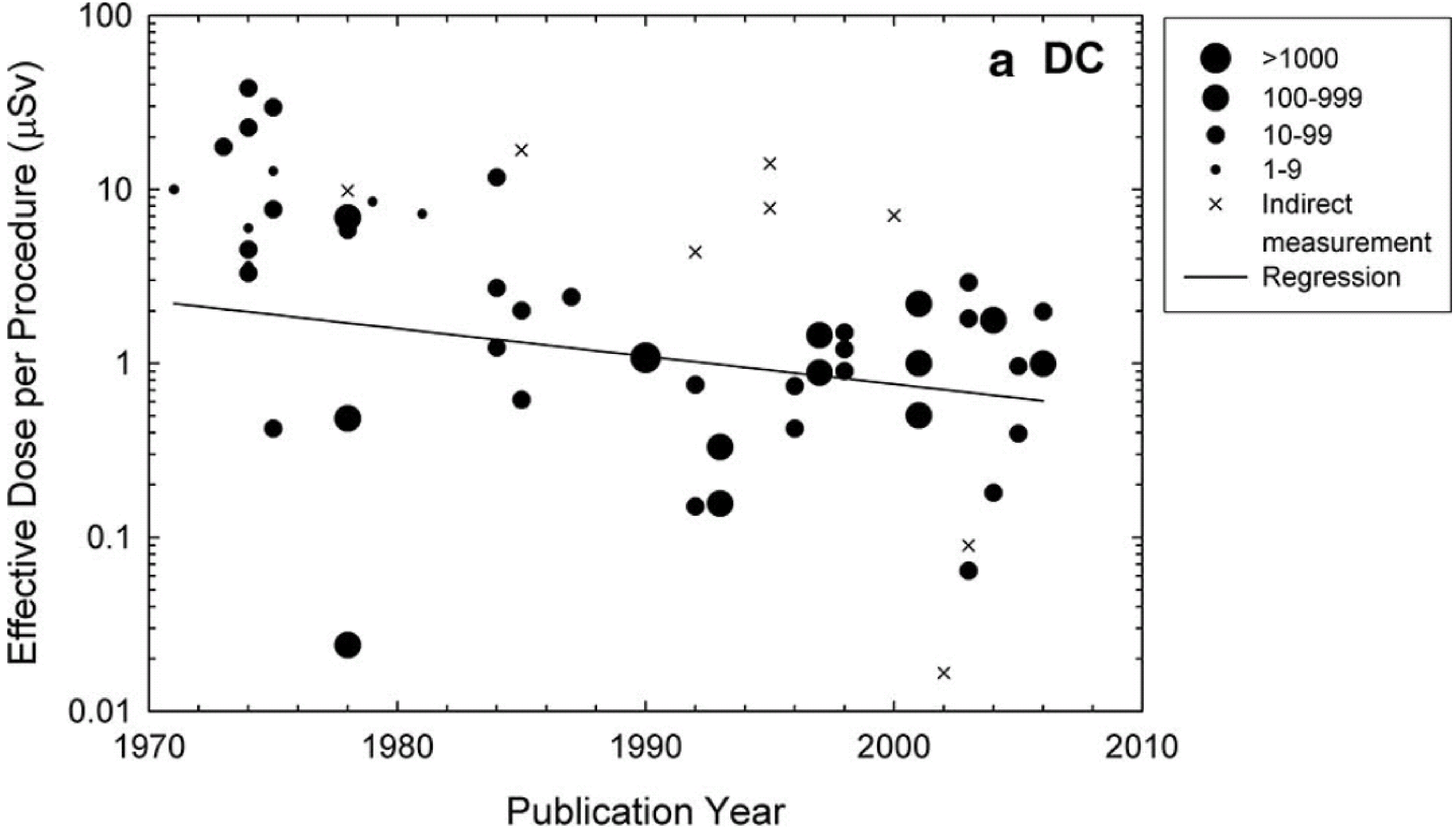
Dose estimation: Operator*



* Kim et al. HP (2008)

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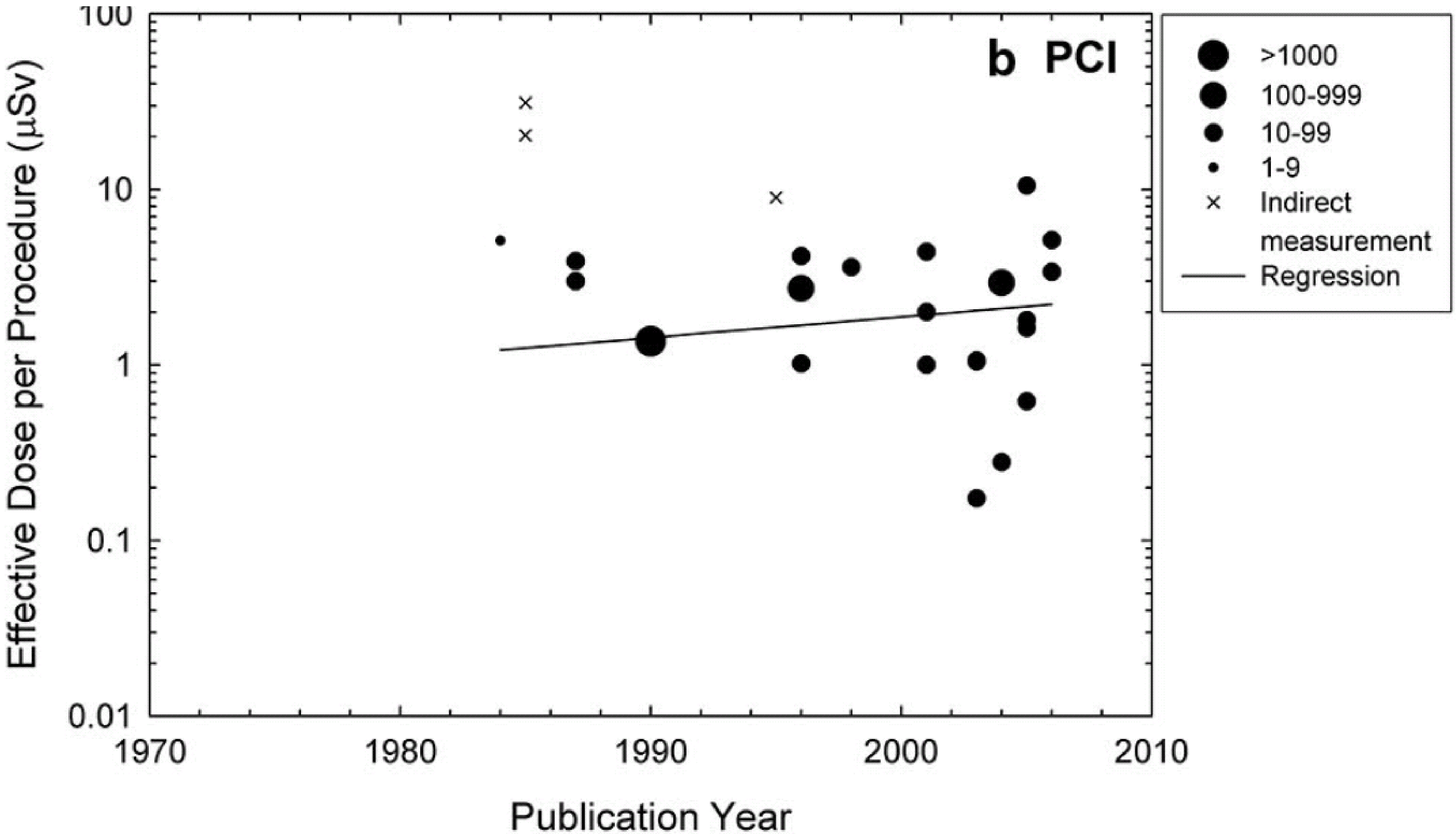
Dose estimation: Operator*



* Kim et al. HP (2008)

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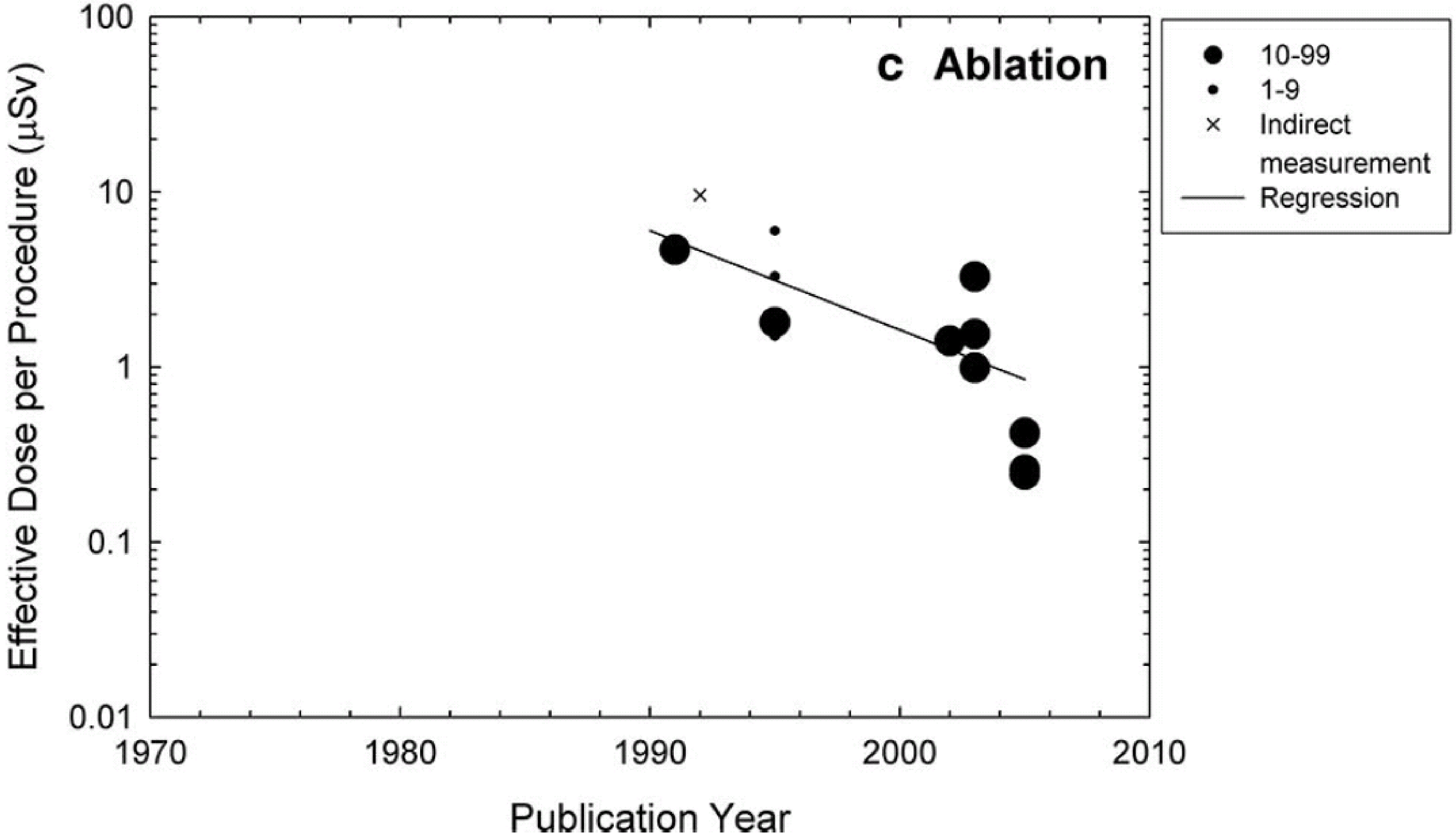
Dose estimation: Operator*



* Kim et al. HP (2008)

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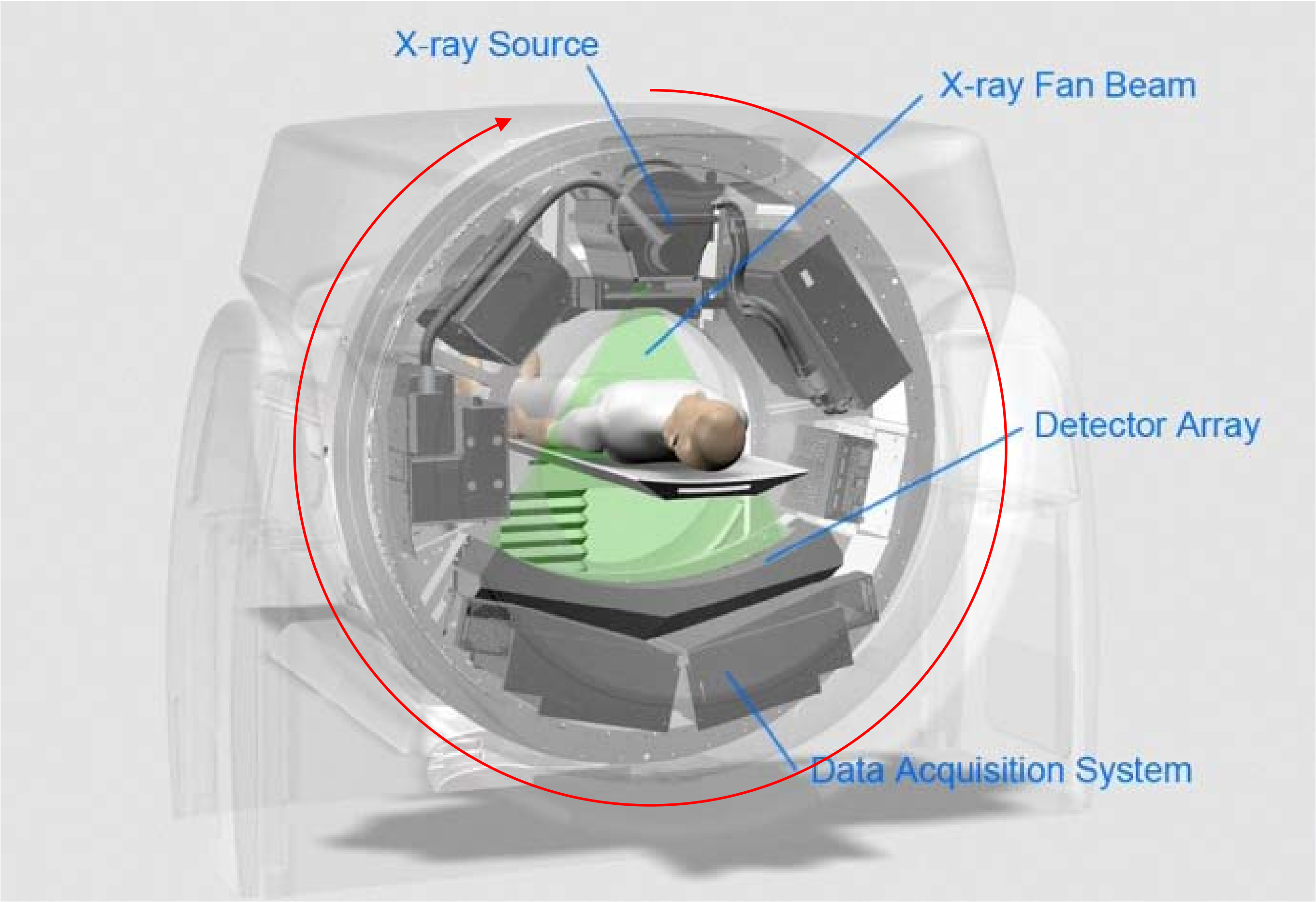
Computed Tomography



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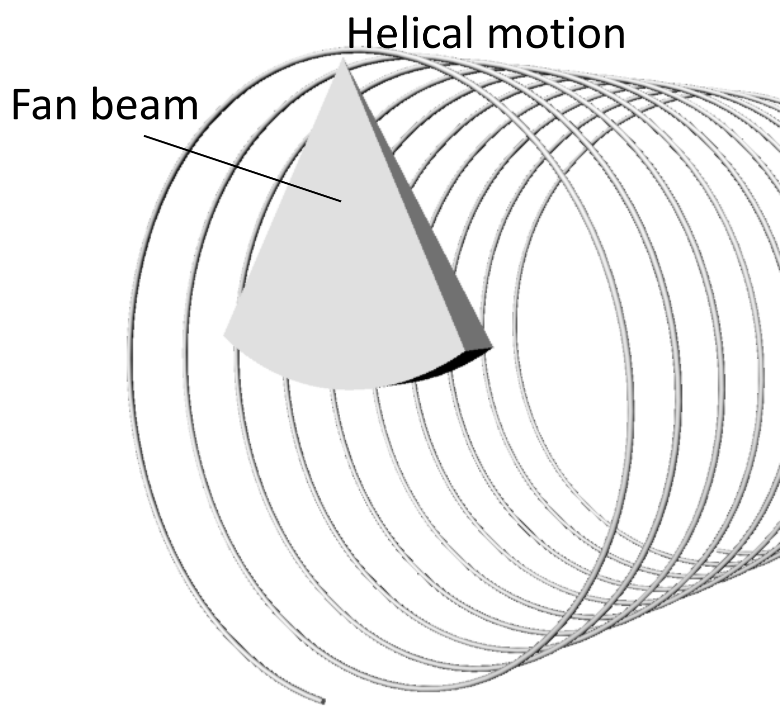
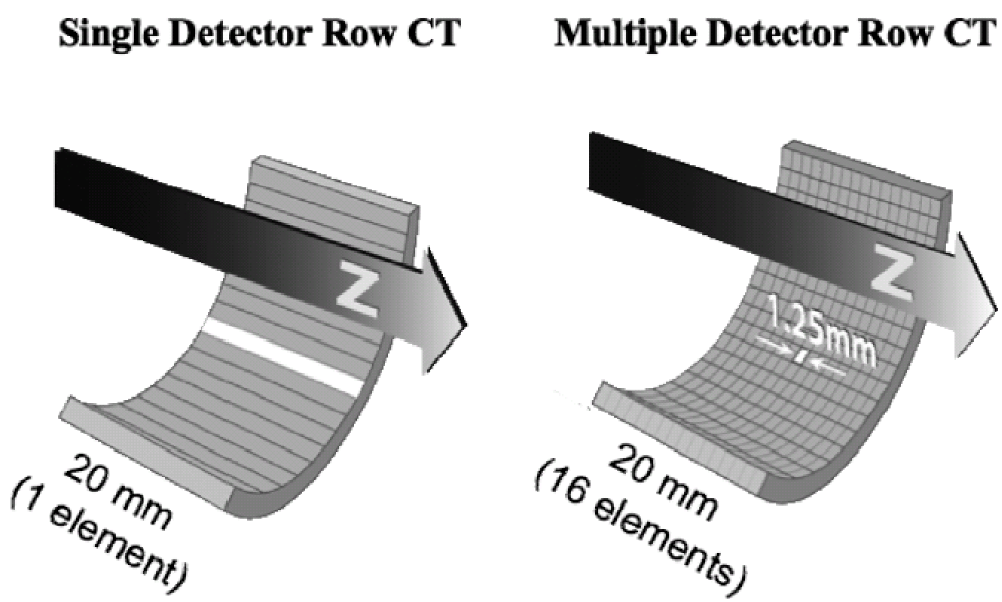
Two innovations in CT





Helical scan:
Faster scan time

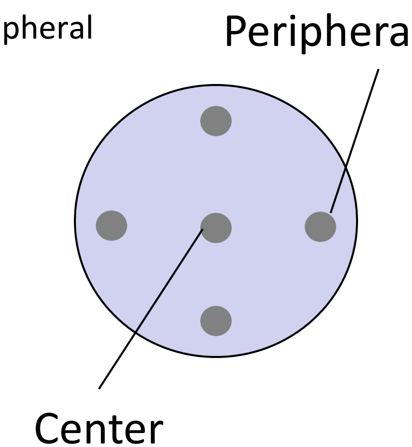
Multi-detector:
More information

Measurable quantities in CT

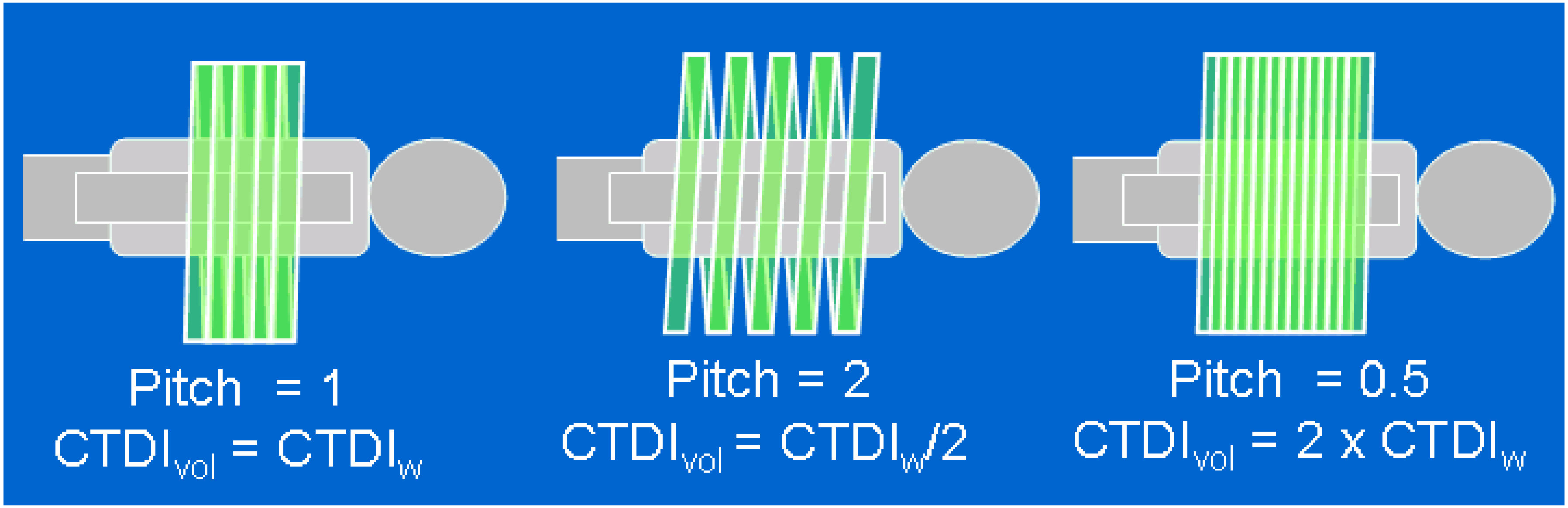
- Computed Tomography Dose Index $(\mathrm{CTDI})_{100}$
  - Single axial rotation
  - 100-mm long ion chamber and head/body CTDI phantoms

- Weighted CTDI: $\mathrm{CTDI}_w = 1/3\ \mathrm{CTDI}_{100,\mathrm{center}} + 2/3\ \mathrm{CTDI}_{100,\mathrm{peripheral}}$
- Volume-weighted CTDI: $\mathrm{CTDI}_{vol} = \mathrm{CTDI}_w$ / pitch
- Dose Length Product (DLP) = CTDI_{vol} x scan length (cm)

- Not designed for or representing patient <u>organ dose!</u>



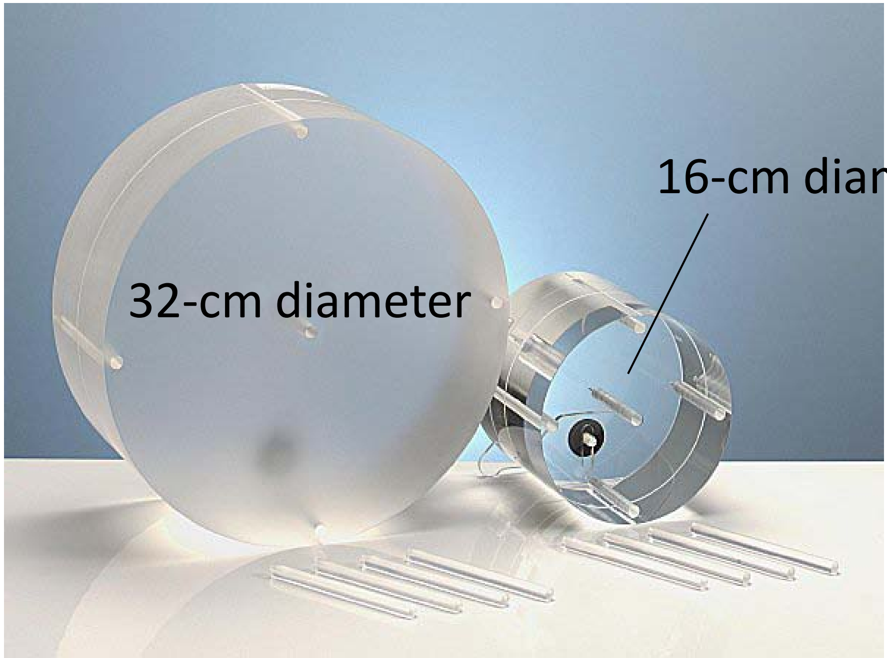
Pitch in helical scan



Volume-weighted CTDI: $CTDI_{vol} = CTDI_w$ / pitch

Factors affecting dose in CT

- Beam energy
- Photon fluence (current-time-product)
- Helical pitch
- Patient size



CTDI body (left) and head (right) phantoms

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Factors affecting dose in CT: Energy

Table 1
Changes in $CTDI_w$ in Head and Body Phantoms as a Function of Kilovolt Peak

Beam Energy (kVp)	$CTDI_w$ in Head Phantom (mGy)	$CTDI_w$ in Body Phantom (mGy)
80	14	5.8
100	26	11
120	40	18
140	55	25

Note.—All other factors were held constant at 300 mA, 1 sec, and 10 mm. Results are from a single-detector CT scanner.

$$14 \times \left(\frac{140}{80} \right)^{2.5} = 56.7$$

* McNitt-Gray Radiographics (2002)

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Factors affecting dose in CT: Fluence (mAs)

Table 2
Changes in $CTDI_w$ in Head and Body Phantoms as a Function of Milliampere-Seconds Setting

Tube Current–Time Product (mAs)	$CTDI_w$ in Head Phantom (mGy)	$CTDI_w$ in Body Phantom (mGy)
100	13	5.7
200	26	12
300	40	18
400	53	23

Note.—All other factors were held constant at 120 kVp and 10 mm. Results are from a single-detector CT scanner.

* McNitt-Gray Radiographics (2002)

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Factors affecting dose in CT: Pitch

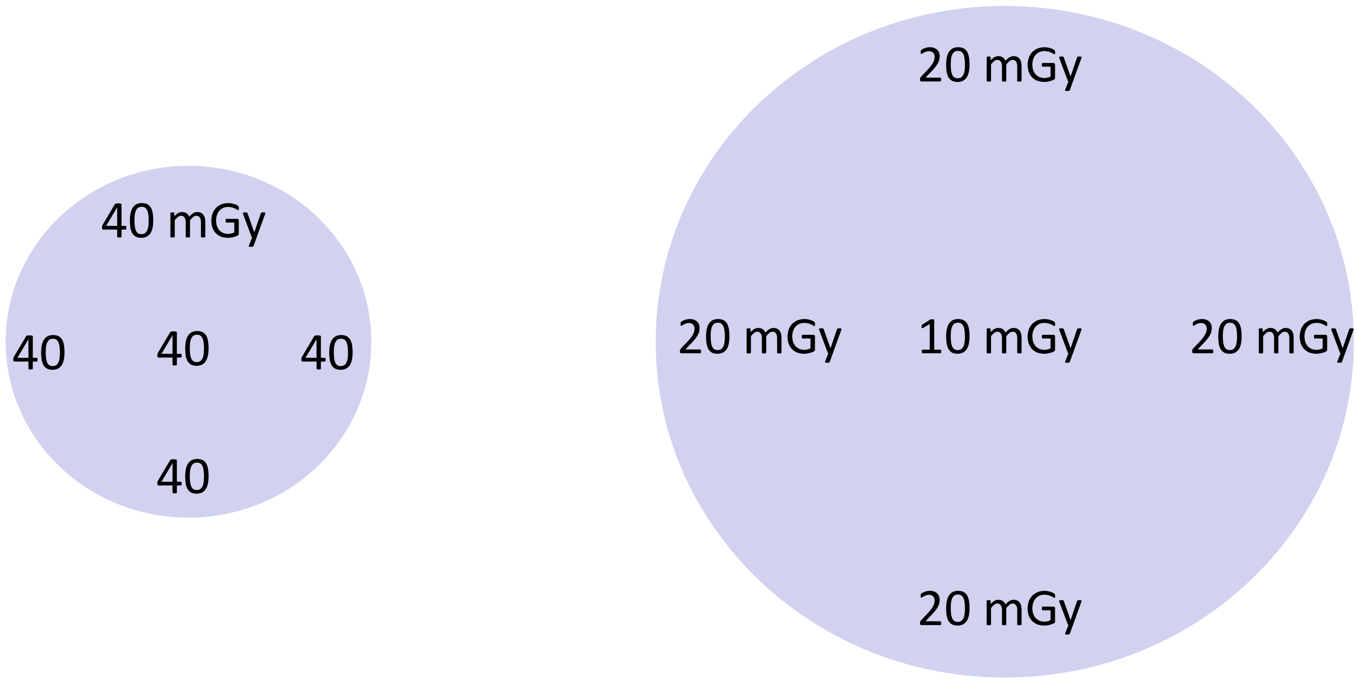
Table 3
Changes in $CTDI_{vol}$ in Head and Body Phantoms as a Function of Pitch

Pitch	$CTDI_{vol}$ in Head Phantom (mGy)	$CTDI_{vol}$ in Body Phantom (mGy)
0.5	80	36
0.75	53	24
1.0	40	18
1.5	27	12
2.0	20	9

Note.—All other factors were held constant at 120 kVp, 300 mA, 1 sec, and 10 mm. Results are from a single-detector CT scanner.

* McNitt-Gray Radiographics (2002)

Factors affecting dose in CT: Patient size*



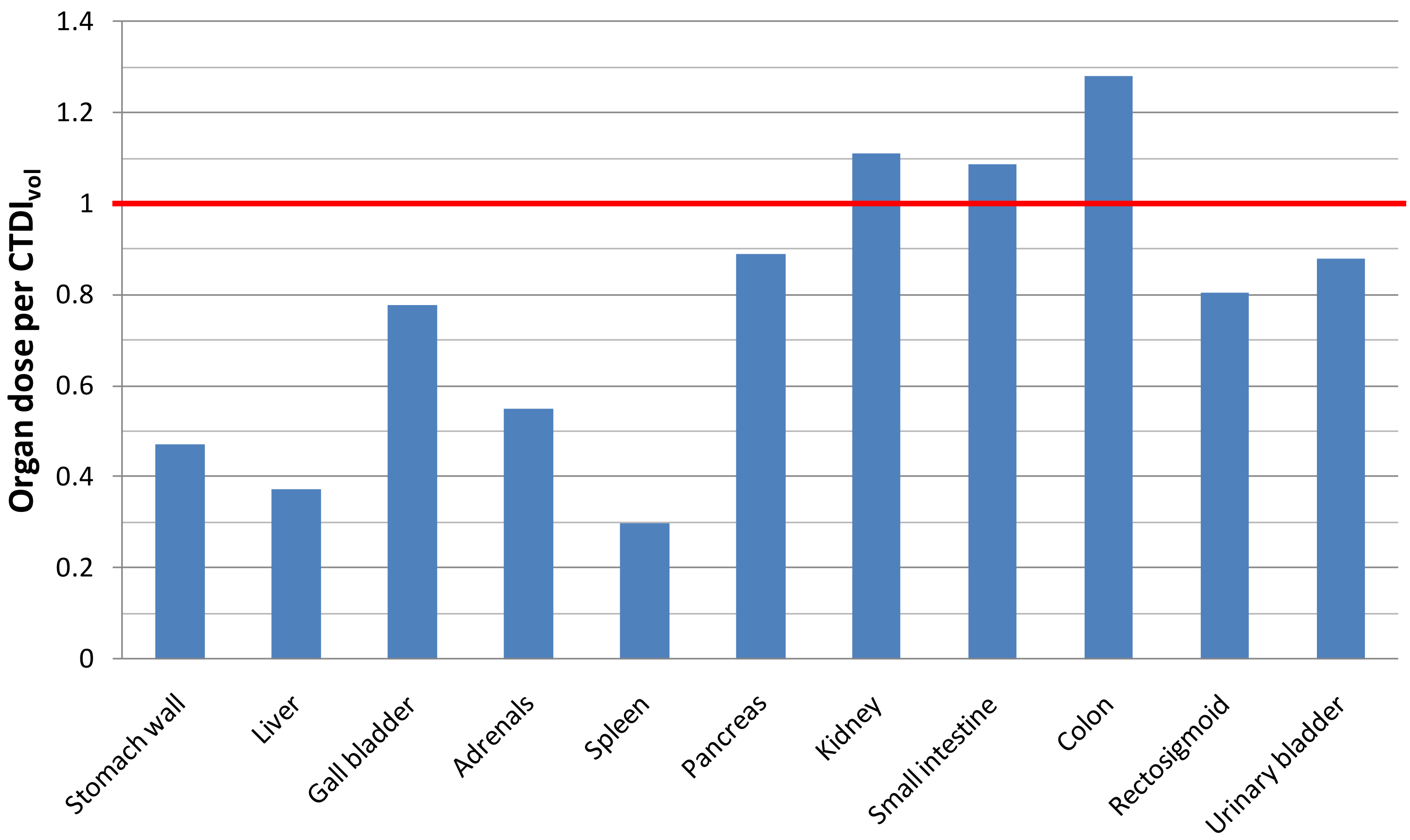
16-cm diameter head phantom

32-cm diameter head phantom

* ImPACT group (http://impactscan.org)

$CTDI_{vol}$ vs. actual organ dose

Organ dose per $CTDI_{vol}$ (abdomen-pelvis scan for adult male)*

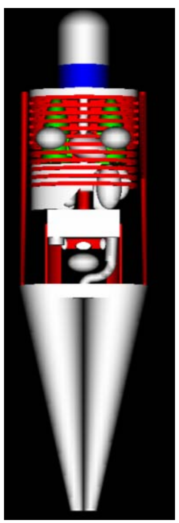


* Lee et al. Medical Physics (2011)

Organ dose estimation: Software tools

ImPACT

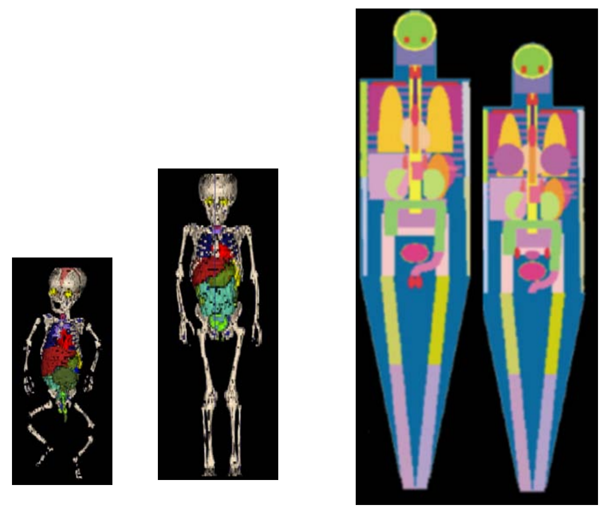
- NRPB database (UK)
- Hermaphrodite adult
- **No children**



ORNL adult hermaphrodite phantom

CT-Expo

- GSF database (Germany)
- Male and female adult
- **Two children**



BABY CHILD ADAM EVA

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ImPACT

ImPACT CT Patient Dosimetry Calculator

Version 1.0.2 12/11/2009

Scanner Model:		
Manufacturer:	Siemens	
Scanner:	Siemens Sensation 16	
kV:	120	
Scan Region:	Head	
Data Set	MCSET21	Update Data Set
Current Data	MCSET21	
Scan range		
Start Position	0	cm
End Position	43	cm

Get From Phantom Diagram

Organ weighting scheme	ICRP 60

Acquisition Parameters:		
Tube current	100	mA
Rotation time	1	s
Spiral pitch	1	
mAs / Rotation	100	mAs
Effective mAs	100	mAs
Collimation		mm
Rel. CTDI (Look up)	1.00	(assumed)
CTDI (air) (Look up)	21.8	mGy/100mAs
CTDI (soft tissue)	23.3	mGy/100mAs
$_nCTDI_w$ (Look up)	16.6	mGy/100mAs

$CTDI_w$	16.6	mGy
$CTDI_{vol}$	16.6	mGy
DLP	713	mGy.cm

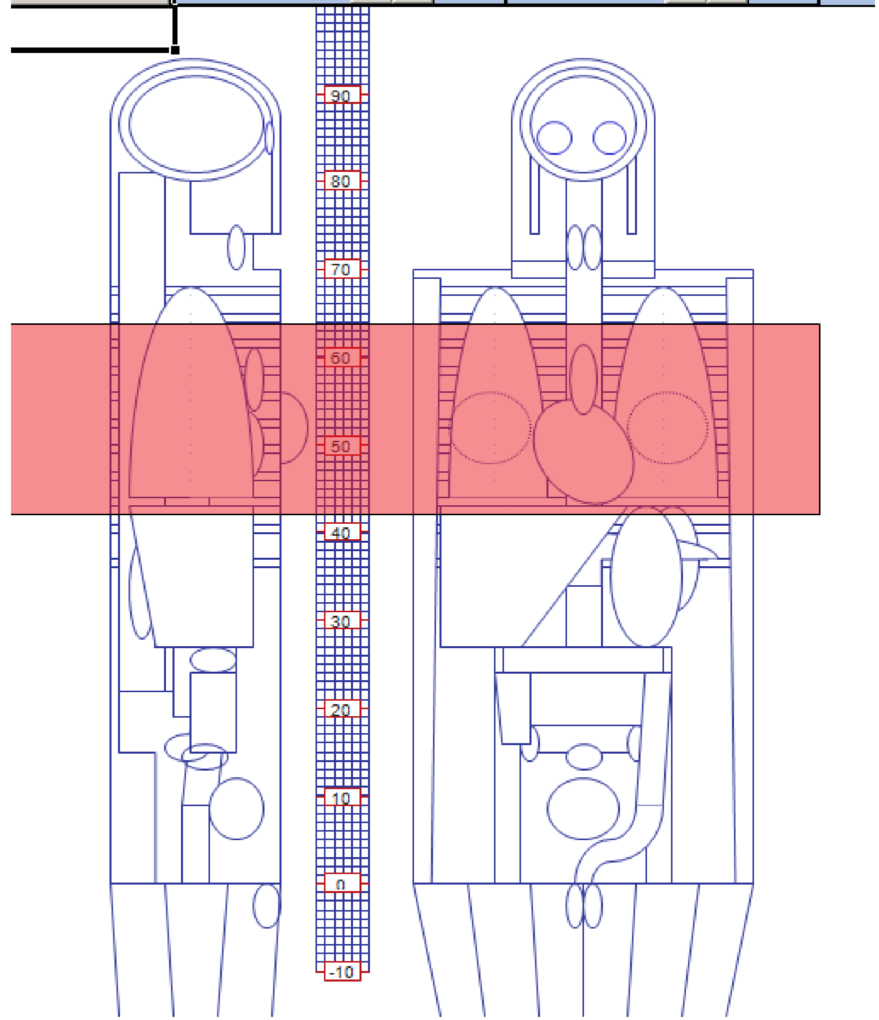
Organ	w_T	H_T (mGy)	$w_T.H_T$
Gonads	0.2	6.5	1.3
Bone Marrow	0.12	4.8	0.57
Colon	0.12	11	1.3
Lung	0.12	1.2	0.15
Stomach	0.12	11	1.3
Bladder	0.05	12	0.61
Breast	0.05	0.35	0.018
Liver	0.05	10	0.5
Oesophagus (Thymus)	0.05	0.26	0.013
Thyroid	0.05	0.031	0.0016
Skin	0.01	3.3	0.033
Bone Surface	0.01	5.8	0.058
Not Applicable	0	0	0
Not Applicable	0	0	0
Remainder	0.025	4.7	0.12
Kidneys	0.025	13	0.31
Total Effective Dose (mSv)			6.3

Remainder Organs	H_T (mGy)
Adrenals	9.4
Small Intestine	11
Kidney	13
Pancreas	9.4
Spleen	10
Thymus	0.26
Uterus	12
Muscle	4.7
Brain	0.0016
Not Applicable	N/A
Not Applicable	N/A
Not Applicable	N/A
Not Applicable	N/A

Other organs of interest	H_T (mGy)
Eye lenses	0.0027
Testes	2.3
Ovaries	11
Uterus	12
Prostate	12

Scan Description / Comments	

Zoom In	Start:	+1	+10	End:	+1	+10
Zoom Out	42.5	-1	-10	64	-1	-10



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Calculate

2. Scan Range

Get Values

Scan Range Data (Slice Positions)		
Scan Range z from z-	to z+	L [cm]
40	70	30

1. Age Group: Adult — Gender: (•) male ( ) female

3. Scanner Model

Manufacturer: General Electric

Scanner: 9800

Scanner Data for Scan Region "Body"

$_nCTDI_w$ [mGy/mAs]	U_{ref} [kV]	$P_{B,H}$	k_{CT}	k_{OB}	ΔL [cm]
0.062	120	0.24	0.50	1.00	0.0

4. Select mode — [ ] Body mode for head/neck region — [x] Spiral mode

5. Scan Parameters

Please Enter Actual Settings:

U [kV]	I [mA]	t [s]	Q_{el} [mAs]	Q [mAs]	$N * h_{col}$ [mm]	TF [mm]	h_{rec} [mm]	p	Ser.
120	120	2	240	0	10.0	10.0	1.0	1.0	1

6. Results

Dose Values per Scan or per Series*

$CTDI_w$ [mGy]	$CTDI_{vol}$ [mGy]	DLP_w* [mGy*cm]	E* [mSv]	D_{uterus}* [mSv]
14.9	14.9	448	6.4	n.a.

Child/Baby: all CTDI and DLP values refer to 16cm head phantom!

Dose Values per Examination

DLP_w [mGy*cm]	E [mSv]	D_{uterus} [mSv]
448	6.4	n.a.

Effective dose E refers to ICRP 60

Please note:
All organ doses H_T are based on conversion coefficients for stand-ard patients (ADAM, EVA, CHILD, BABY) and serve for information purposes only (in particular organs outside the scan range)!

Tissue or Organ	H_T per Series [mSv]	Remainder Organs	H_T per Series [mSv]
Thyroid	6.4	Brain	0.3
Breasts	0.0	Thymus	22.7
Oesophagus	22.7	Spleen	5.8
Lungs	23.4	Pancreas	5.2
Liver	7.4	Adrenals	9.3
Stomach	4.8	Kidneys	1.5
Colon	0.0	Small intest.	0.2
Testicles	0.0	Upp. large int.	0.3
Ovaries	0.0	Uterus	0.0
Bladder	0.0		
Bone marrow	5.6	**Misc.**	**H_T per Series** [mSv]
Bone surface	15.0		
Skin	5.4	Eye lenses	0.4

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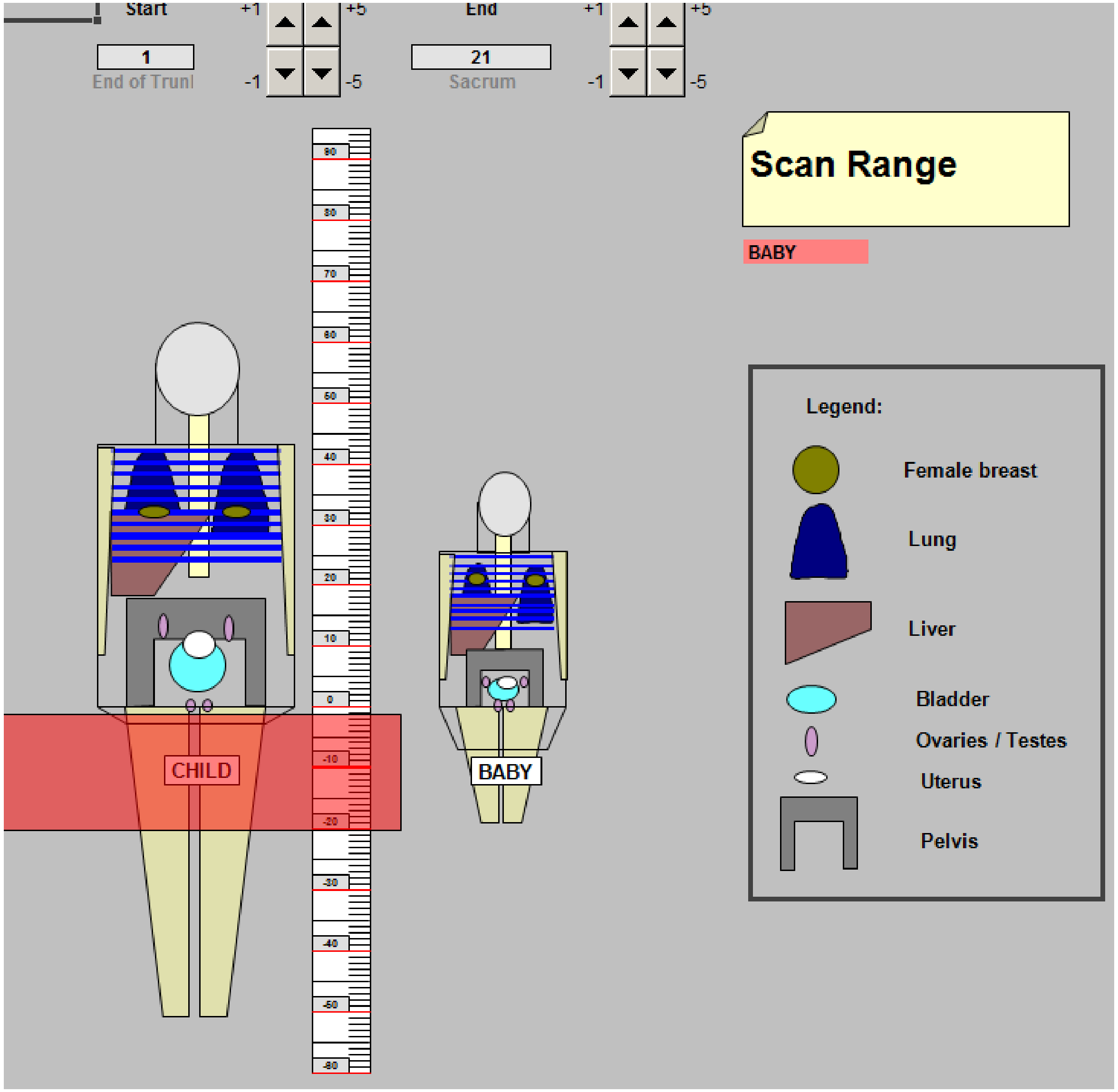

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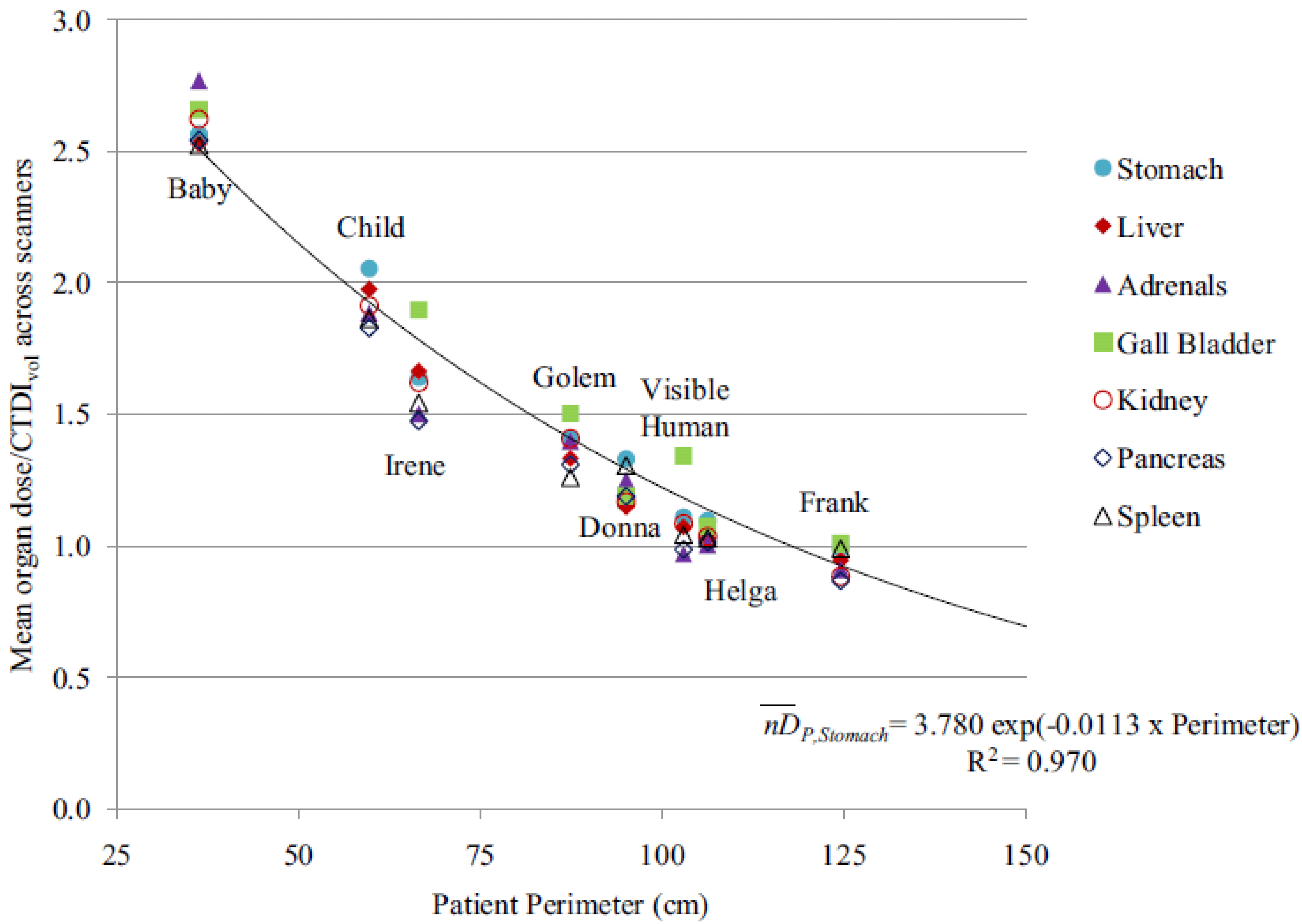
Organ dose estimation: Perimeter-base*



* Turner et al. MP (2011)

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Perimeter-based organ doses*

TABLE II. Results of exponential regression analysis describing $\overline{nD}_{P,O}$ as a function of perimeter (cm) for fully irradiated organs.

	Exponential regression coefficients		Correlation coefficient
Organs	A_O	B_O	R^2
Liver	3.824	−0.0120	0.98
Stomach	3.780	−0.0113	0.97
Adrenals	4.029	−0.0128	0.95
Kidney	3.969	−0.0124	0.99
Pancreas	3.715	−0.0122	0.97
Spleen	3.514	−0.0111	0.95
Gall bladder	3.994	−0.0115	0.95

* Turner et al. MP (2011)

Summary

- Epidemiology needs individualized organ dose.
- Three approaches
  - Measurement: expensive, labor-intensive, and not individualized
  - Calculation: cost-effective, fewer man-hour, and individualized
  - Conversion factor: derived from calculation
- Four different imaging modalities
  - Radiography
  - Mammography
  - Fluoroscopy
  - Computed Tomography

References

- Parry RA, Glaze SA, and Archer BR 1999 The AAPM/RSNA Physics Tutorial for Residents. Radiographics **19(5) 1289-1302**

- McNitt-Gray MF 2002 AAPM/RSNA physics tutorial for residents: topics in CT. Radiographics **22(6) 1541**

Thank you for your attention!
Any questions or comments appreciated